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MAY 2023

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- OUR STELLAR NEIGHBOURS DUE TO EXPLODE

"NO ONE KNOWS WHAT THIS EXPLOSION IS"
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WELCOME

ISSUE 142

It's said that the very first supernova was recorded in 4500 BCE – give or take 1,000 years – by Indian astronomers. The stellar explosion, which has been dubbed HB9, would mark one of the very first events to cause humankind to look to the heavens, wondering – and then likely investigating – what lay beyond the confines of planet Earth. This issue, you'll discover where we're at in our understanding of supernovae. Our experts have details of what causes them, how they can give rise to life and what stellar candidates are next to end their lives in our corner of the universe. And that's not all... we'll reveal the pieces of information astrophysicists are just itching to find out.

The summer months are almost upon us. While that does mean lighter evenings and mornings, there's still plenty to see in the night sky, especially if you choose to stay up late. From star clusters and galaxies to nebulae and planets, I'll leave you to get acquainted with some of my firm night-sky favourites. Don't forget, you can share your images with the **All About Space** team via our contact details below, whether you prefer social media or email. I'll look forward to seeing you next time!

GEMMA LAVENDER
Editor

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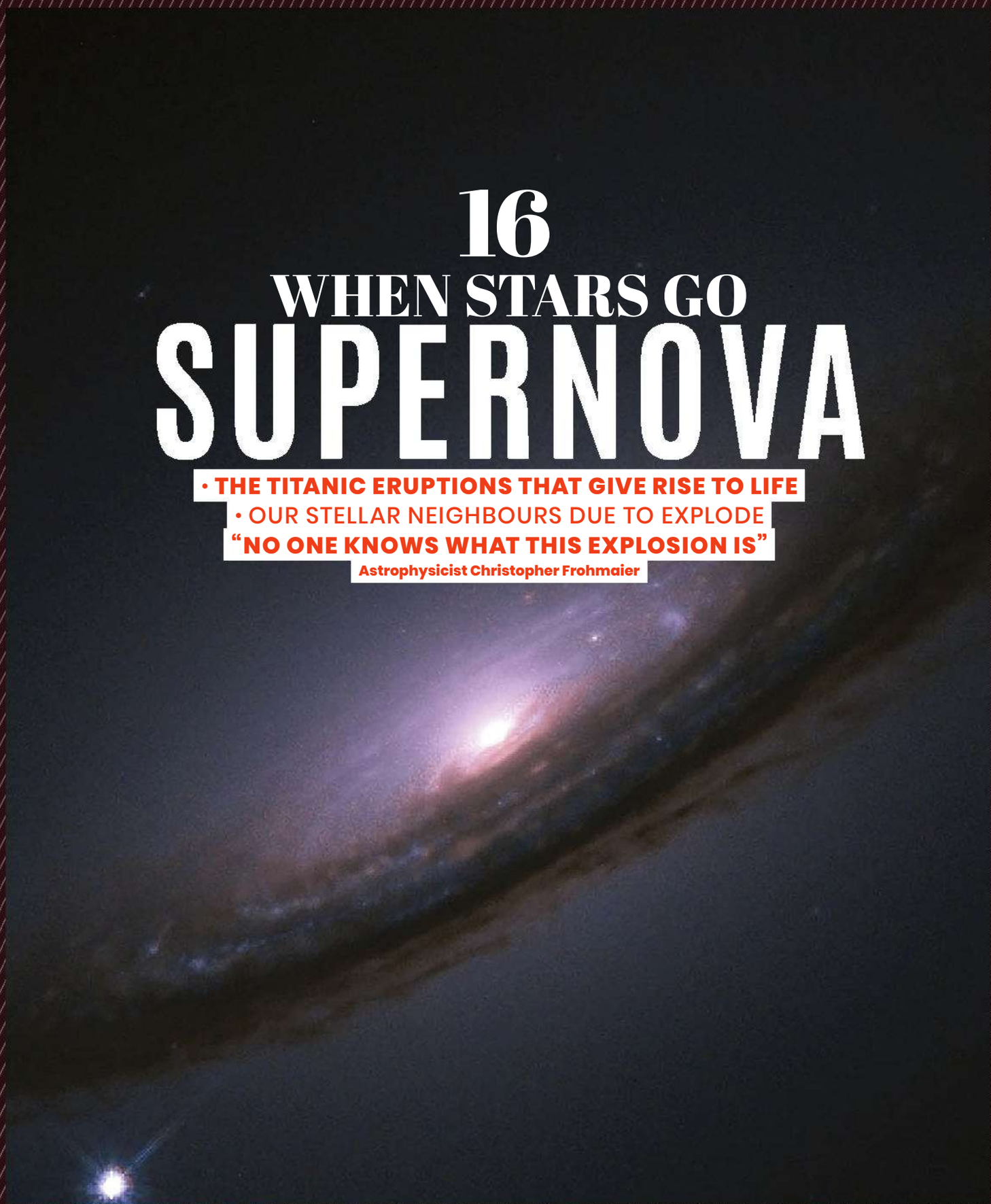

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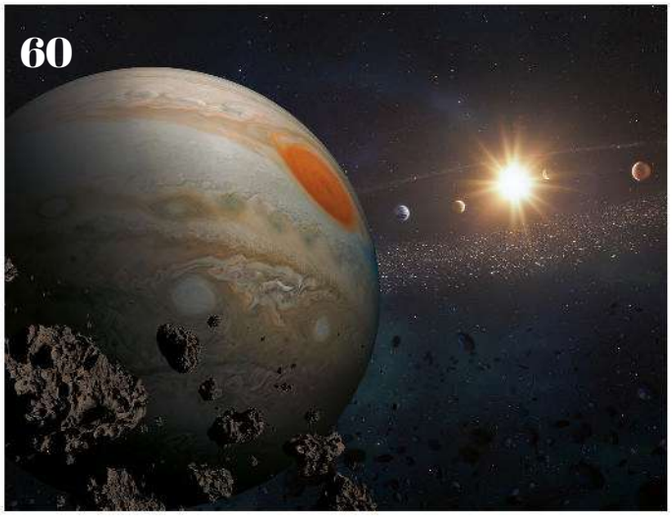

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8 February 2023

Curiosity finds clues to Mars' watery past

NASA's Curiosity rover has found rocks imprinted with tiny ripples from an ancient lake. They're the clearest evidence yet that water once existed on Mars. The ripple marks were discovered frozen in Martian rock on the slopes of Mount Sharp. Though Curiosity has traversed many rock deposits laid down in ancient lakes, scientists hadn't seen such vivid marks in the rocks before. "This is the best evidence of water and waves that we've seen in the entire mission," Ashwin Vasavada, Curiosity's project scientist at NASA's Jet Propulsion Laboratory, said. "We climbed through thousands of feet of lake deposits and never saw evidence like this, and now we've found it in a place we expected to be dry."

Since last autumn the rover has been exploring a region of what scientists call 'sulphate-bearing' rock. Scientists believe this salt-rich area was deposited when an ancient lake was nearly dry. But the ripples were created on the bottom of a shallow lake as winds created waves on the lake's surface, disturbing the sediments below. The ripple marks are about 0.8 kilometres (0.5 miles) up Mount Sharp, a mountain made up of layers of rock that record Martian history. The five-kilometre (three-mile) mountain was once dotted with lakes and streams, making it an intriguing area to search for signs of ancient Martian life.

The presence of ripples in a supposedly dry area suggests that Mars did not go from wet to dry in a simple, linear manner, the Curiosity researchers said. Near the rippled rocks, researchers also saw rock layers with regular spacing and thickness. These types of layers often occur on Earth during patterns of periodic change.

© NASA; JPL-Caltech;

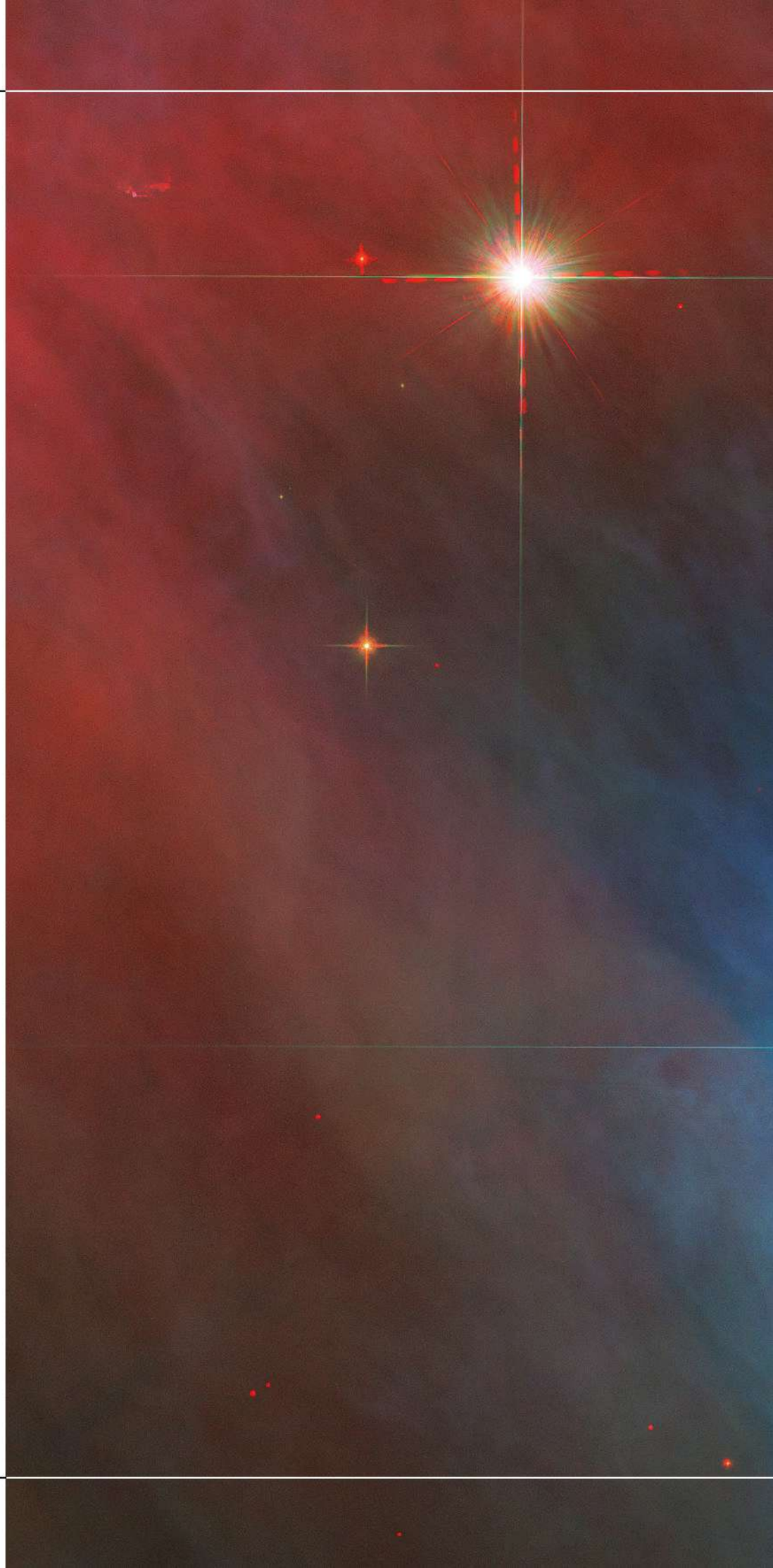
23 January 2023

Hubble captures a stunning stellar duo

The Hubble Space Telescope captured a dazzling new view of two tempestuous young stars in the nearby Orion Nebula. A bright variable star known as V 372 Orionis is the larger central star surrounded by hazy blue clouds in the recent Hubble photo, while its companion star can be seen to the upper left. These stars reside in the Orion Nebula, a region of stellar formation located around 1,450 light years away from Earth.

"V 372 Orionis is a particular type of variable star known as an Orion variable. These young stars experience some tempestuous moods and growing pains, which are visible to astronomers as irregular variations in luminosity," European Space Agency (ESA) officials said. "Orion variables are often associated with diffuse nebulae, and V 372 Orionis is no exception – the patchy gas and dust of the Orion Nebula pervade this scene."

This new Hubble image combines data from two of the space telescope's instruments: the Advanced Camera for Surveys and the Wide Field Camera 3. Researchers used data taken at both infrared and visible wavelengths to create this overlay image, which reveals details of the nebula. The bright stars are surrounded by diffraction spikes, which occur when an intense source of light interacts with the four vanes inside Hubble that support the telescope's secondary mirror. The four spikes seen around the brightest stars are specific to Hubble's internal structure. By comparison, the James Webb Space Telescope creates six-pointed diffraction spikes due to its hexagonal mirror segments and three-legged support structure for the secondary mirror.



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16 February 2023

Baby stars dance in galactic gas and dust

This image from the James Webb Space Telescope shows the arms of barred spiral galaxy NGC 1433 teeming with young stars that can be seen affecting the clouds of gas and dust around them. The snap was taken as part of the Physics at High Angular resolution in Nearby GalaxieS (PHANGS) collaboration, of which more than 100 researchers around the world are a part. One of Webb's first science programs is to image 19 spiral galaxies for PHANGS with its Mid-Infrared Instrument (MIRI), capable of seeing through gas and dust clouds that are impenetrable with other types of imaging. "The PHANGS team has spent years observing these galaxies at optical, radio and ultraviolet wavelengths using NASA's Hubble Space Telescope, the Atacama Large Millimeter/Submillimeter Array and the Very Large Telescope's Multi Unit Spectroscopic Explorer," PHANGS team member Adam Leroy of Ohio State University said. "But the earliest stages of a star's life cycle have remained out of view because the process is enshrouded within gas and dust clouds."

In the MIRI observations of NGC 1365, clumps of dust and gas in the interstellar medium have absorbed the light from forming stars and emitted it back out in the infrared, lighting up an intricate network of cavernous bubbles and filamentary shells created by young stars releasing energy into the galaxy's spiral arms. "Areas which are completely dark in Hubble imaging light up in exquisite detail in these new infrared images, allowing us to study how the dust in the interstellar medium has absorbed the light from forming stars and emitted it back out in the infrared, illuminating an intricate network of gas and dust," said PHANGS team member Karin Sandstrom of the University of California, San Diego.

© NASA; ESA

Big asteroids hit Earth more frequently than was thought

Reported by Elizabeth Howell

A fresh asteroid-strike study is generating controversy among scientists. A NASA-funded study presented at the Lunar and Planetary Science Conference suggests that big asteroids hit Earth more often than previously thought, based on satellite data. But not everyone agrees with the interpretation, according to the journal *Science*, which says more fieldwork is needed to confirm the data. The study was led by James Garvin, chief scientist of NASA's Goddard Space Flight Center in Maryland, and used high-resolution data from several Earth-observing satellites to examine three impact craters. Garvin's team suggests that large rings are visible in the data, showing that the craters are tens of miles wider than previously measured. That size adjustment implies that the impacts were far more powerful than previously catalogued. "It would be in the range of serious stuff happening," Garvin said during the presentation, held in the Woodlands, Texas.

Calculating the impact rates of asteroids is a difficult science – many incoming space rocks burn up in Earth's atmosphere, and wind and water erode the marks left by asteroids that do manage to make it to the ground. Figuring out how often the Moon or Mars is pummelled is also difficult, as the rate may vary over time. Similarly, assessing threatening asteroids has its issues, although scientists can say with certainty that no big asteroids pose a threat to Earth for the foreseeable future.

Generally speaking, researchers estimate that a space rock at least one kilometre (0.62 miles) wide hits Earth about every 600,000 or 700,000 years. But the new study ramps up the rate considerably, suggesting that four objects of that size smacked into Earth in the last million years. In conversations with other researchers at the conference, however, *Science* learned that they were urging more critical examination of the results before fully revising all of our estimates for space rock encounters. Anna Łosiak, who researches craters at the Polish Academy of Sciences, said the rings identified in the new study may not be crater features after all. If they truly are, she added, the implications are worrisome because "there are a lot of space rocks that may come and make a mess." Similarly, Canadian planetary scientist Gordon Osinski, a University of Western Ontario professor leading the science team on the country's forthcoming lunar rover, said he couldn't conclusively identify rims in the study's data. "Those features are so subtle that I don't think they say 'big structural rim'," he said.

Garvin's team based its work on the ICESat-2 satellite, the Global Ecosystem Dynamics Investigation instrument on the International Space Station and commercial stereo imaging available from private companies Planet and Maxar. The scientists argue that the newer data, given their higher resolution of four metres (13 feet) or less, is a "major improvement over existing topography" used for impact calculations, like NASADEM and Germany's TanDEM-X SAR, which offer 30 metres (100 feet) and 12 metres (40 feet) resolution respectively. Garvin said that without fieldwork, "we haven't proven anything," which was echoed in yet another conversation with Bill Bottke, a planetary dynamicist at the Southwest Research Institute in Boulder, Colorado. "I'm sceptical. I want to see a lot more before I believe it," Bottke said.

Meteor Crater near Winslow, Arizona, was blasted out by a roughly 50-metre (165-foot) wide impactor about 50,000 years ago

Sea level rise slowed down in 2022, but NASA says it's just a blip

Reported by Tereza Pultarova

Global sea levels rose more slowly in 2022 than models predicted. But there's no reason to celebrate, at least according to NASA. The minor deviation from a decades-long trend was caused by the cooling effects of the La Niña climate pattern, and we are no doubt set to see faster sea level rise again in the coming years. Between 2021 and 2022, global oceans absorbed the equivalent of a million Olympic-sized swimming pools of water, which added 0.27 centimetres (0.11 inches) to average global sea levels. This increase is 0.17 centimetres (0.05 inches) lower than the projected 0.44-centimetre (0.17-inch) rise that scientists expected last year.

Despite such fluctuations, 30 years' worth of satellite measurements reveal a trend of sea level rise acceleration that's only expected to speed up. While in the 1990s global sea levels were rising at 0.20 centimetres (0.08 inches) per year, by 2050, three times as much water will be added to the global oceans on a yearly basis. Scientists link the slowdown observed in 2022 to the La Niña climate pattern – the cold counterpart of El Niño. During La Niña years, sea surface temperatures in the Pacific Ocean drop, and this change has widespread effects on weather around the world, including on the amount of rainfall above the oceans. But weather forecasters expect the warming El Niño to return in 2023, and with it, the sea level rise is set to speed up again.

NASA's data revealed that since 1993, global sea levels have risen by 9.1 centimetres (3.6 inches). NASA has been monitoring sea surface height since it launched the first satellite capable of measuring sea levels in 1992 in cooperation with its French counterpart, the National Centre for Space Studies CNES. The view from space allowed scientists to gain a detailed and global overview of what was happening with the world's oceans. "We have this clear view of recent sea level rise – and can better project how much and how quickly the oceans will continue to rise – because NASA and CNES have gathered decades of ocean observations," Karen St. Germain, director of NASA's Earth Science Division in Washington, said. "By combining that data with measurements from the rest of the NASA fleet, we can also understand why the ocean is rising."

Although natural weather fluctuations such as La Niña can have an effect on sea surface height, scientists know that the main contributor to accelerating sea level rise is human-made climate change. Because of rising temperatures, ice sheets and glaciers melt faster, and more fresh water flows into the seas. On top of that, the warmer temperatures lead to the expansion of sea water, which further exacerbates the rise of sea levels.

A NASA satellites have been monitoring global sea level rise since 1993

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Two moons of Uranus may have active subsurface oceans

Reported by Robert Lea

Two of Uranus' moons may have active oceans that are pumping material into space. The realisation that there may be more happening in the Uranus system than previously thought came via the discovery of strange features in radiation data collected by NASA's Voyager 2 spacecraft as it passed the planet almost four decades ago. The new findings, concerning the moons Ariel and Miranda, also support the idea that Uranus' five largest satellites could have subsurface oceans. The study team examined radiation and magnetic data collected by the spacecraft in 1986, long before it made its way out of the Solar System.

The newly reported observations of Voyager 2 showed that one or two of the ice giant's 27 known moons are adding plasma particles into the Uranus system. This detection came in the form of 'trapped' energetic particles the spacecraft spotted as it departed the ice giant. The mechanism by which Miranda and/or Ariel may be doing this is unknown, but there's a very tantalising possible cause: one or both of the moons may possess a liquid ocean beneath their frozen surface that's actively blasting plumes of material into space.

Similar particle-releasing moons exist around Uranus' fellow Solar System ice giant Neptune and the gas giants Jupiter and Saturn. In the case of the Jupiter moon Europa and Saturn's Enceladus, it was the examination of particle and magnetic field data that provided the first hints these are ocean moons. "It isn't uncommon that energetic particle measurements are a forerunner to discovering an ocean world," Ian Cohen, a space scientist at the Johns Hopkins Applied Physics Laboratory (APL) in Laurel, Maryland, said.

Artist's impression of Uranus as seen from Ariel

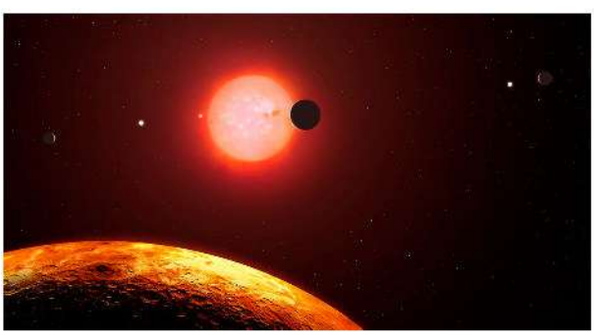
Even calm red dwarf stars rage more violently than the Sun

Reported by Robert Lea

A new study of red dwarf stars has revealed that even the quietest examples of this stellar class are more active and wild than the Sun. Red dwarfs, officially known as 'M dwarfs' by astronomers, are the most common stars in the Milky Way and can remain placid for long periods of time before erupting with huge superflares. These flares have previously been measured to be 100 to 1,000 times more powerful than similar flares from the Sun, with young red dwarfs being particularly tumultuous. These outbursts, as well as eruptions of scorching-hot plasma known as coronal mass ejections (CMES), can be incredibly destructive to planets orbiting red dwarfs, stripping their atmospheres and emitting enough radiation to boil away liquid water even in the so-called habitable zone around them – the region around a star in which liquid water can exist on a world's surface.

Such high activity might therefore make it tough for life to take root around red dwarfs. One system that astronomers are particularly keen to search for potential signs of life is TRAPPIST-1, which contains seven roughly Earth-sized planets, at least three of which are in the habitable zone. But TRAPPIST-1 is a red dwarf, and if it erupts with violent flares like fellow red dwarf Proxima Centauri, which in 2019 emitted a flare 14,000 times brighter than its pre-flare brightness, then TRAPPIST-1's life-hosting potential may be relatively low.

The team behind the new study, including scientists from France, Portugal and Switzerland, looked at observations of 177 red dwarfs collected between 2003 and 2020 by the High Accuracy Radial velocity Planet Searcher (HARPS), an instrument on the 3.6-metre telescope at the European Southern Observatory's La Silla Observatory. This allowed them to characterise the long-term variability of these red dwarf stars.



Planets orbiting a red dwarf

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WHEN STARS GO SUPERNOVA

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"NO ONE KNOWS WHAT THIS EXPLOSION IS"

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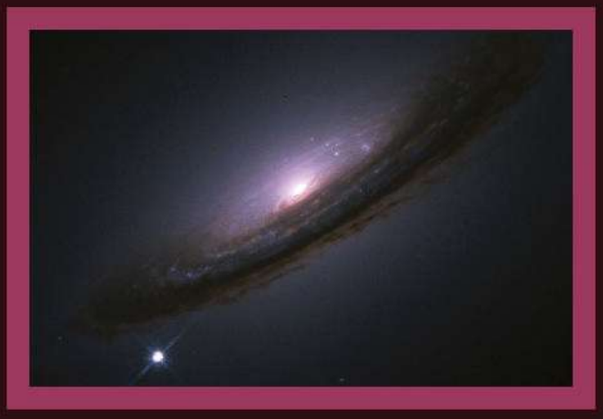


Place your fingers on your wrist and check your pulse. You can feel the blood pumping around your body, delivering oxygen from your head to your toes. That oxygen is ferried around by trillions of red blood cells, each just 0.008 millimetres across. The element iron plays an indispensable role in this oxygen delivery, but the universe would contain very little iron if it weren't for a ferocious type of exploding dying star called a supernova. Without supernovae, you simply wouldn't exist.

We often think of the Sun as the quintessential star, but it's not massive enough to go supernova when it dies. According to Dr Christopher Frohmaier, a supernova researcher at the University of Southampton, to detonate in this most spectacular of celestial firework displays, a star needs a starting mass equivalent to at least eight Suns. The path that these massive stars follow towards their eventual demise as a supernova is inevitable. It's triggered by a fundamental shift in the interplay between the outward pressure generated by the nuclear fusion reactions in the star's core and gravity. "Throughout a massive star's life, it's in a constant balance between these forces," says Frohmaier.

Things begin to change when the hydrogen that sustains the nuclear reactions runs out. "The star will burn sequentially heavier and heavier elements to support its outer layers," Frohmaier says. Nested shells of helium, carbon, oxygen, neon, magnesium and silicon build up as the star exhausts its supply of successive elements and desperately scrambles for something new to burn. Eventually, the star's nuclear reactions produce iron from the silicon, which builds up the middle of the core. "The phase of converting silicon to iron can be over in a matter of hours," Frohmaier says. That compares to perhaps billions of years burning hydrogen into helium.

It's at this point that the nuclear reactions switch off. Iron is the most stable element in the periodic table – burning iron requires more energy to go in than comes out, and so it simply doesn't happen. Now unsupported, the star's outer layers come crashing down, building up an intense pressure on the core that breaks the iron back down into helium. "It's called photodisintegration," Frohmaier says. "And it also creates an overwhelmingly large number of neutrinos."

Neutrinos are tiny, almost-massless subatomic particles. The photodisintegration of the iron core creates approximately 10 billion trillion trillion trillion trillion neutrinos. "The neutrinos are blown outwards and drive the supernova explosion by pushing against the star's outer layers," Frohmaier explains. It's a slightly surreal role for neutrinos to play, as they are famously very antisocial particles. You would need a light year of lead to have a 50:50 chance of halting a single neutrino, yet there are so many produced by photodisintegration that their collective power blasts an entire massive star apart. In a short ten-second salvo, the neutrinos release almost a quadrillion quadrillion quadrillion Joules of energy. That's about the same amount of energy as the Sun will release in its entire 10-billion-year lifetime.

Astronomers call supernovae like these core-collapse supernovae. However, despite the huge amount of energy they release, when astronomers spot a core-collapse supernova in the night sky, they aren't observing the light from the explosion itself. "What we are seeing is radioactive decay," Frohmaier says. The supernova produces vast amounts of a rare form of the element nickel, known as nickel-56. It's unstable, and so breaks down – or decays – into cobalt and iron. This process creates a lot of gamma rays – the most energetic form of light. "All the material thrown out from the explosion gets energised by those gamma rays," says Frohmaier. That material then glows with visible light, which is what lights up the night sky and alerts astronomers to the death of a massive star.

A Type Ia supernova shining as brightly as the centre of the galaxy it's in

© Alamy; NASA/ESA;

And that light can be searingly bright. In 1054, Chinese astronomers wrote about a 'guest star' that suddenly appeared in the sky. It was so bright that it could be seen during the day for a month and took almost two years to fade from the night sky. Today we know that they witnessed a supernova explosion, the remnants of which form the Crab Nebula (Messier 1) in the constellation of Taurus, the Bull. Betelgeuse, not too far away in the constellation of Orion, will do something similar in the future. Astronomers can get deeper insights into the mechanics of supernovae by breaking up their light into spectra, much like how a raindrop splits sunlight to create a rainbow. Hidden within this stellar spectrum are so-called absorption features that point to the presence of various elements within the debris from the supernova. All supernovae with hydrogen in their spectra are classed as Type II supernovae.

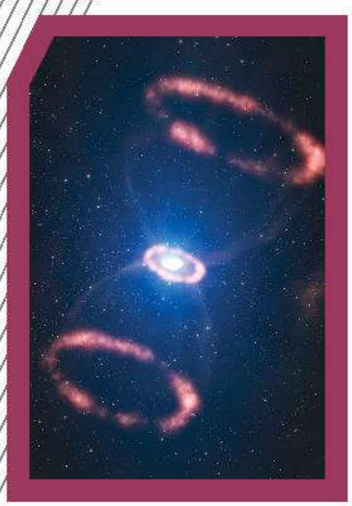
There's a separate class of supernovae, known as Type I, that don't have hydrogen in their spectra. For Type Ib, that's because fierce winds blew the hydrogen outwards from the star before it collapsed. For Type Ic the star also blew its helium away, meaning there's no hydrogen or helium present in the spectrum. These are still core-collapse supernovae, though. But by far the most famous Type I supernova – known as Type Ia – has a completely different origin. "No one knows exactly what the explosion mechanism is," Frohmaier says, although all options point towards another remnant of dead stars: white dwarfs.

Stars that start off less massive than eight Suns aren't big enough to trigger core-collapse supernovae. These stars move from burning hydrogen to burning helium, eventually fashioning a core of carbon and oxygen about the same size as Earth... a white dwarf. There isn't sufficient pressure to fuse carbon, so why doesn't a white dwarf collapse? "White dwarfs aren't supported by fusion, but by something called degeneracy pressure," Frohmaier says. There's a rule in quantum physics that says it's impossible to force certain particles into the same state, so try as it might to collapse, a white dwarf cannot.

There's a limit to how massive a white dwarf can be, however. "If you exert too much pressure then the temperature will rapidly increase and the carbon will undergo thermonuclear runaway," Frohmaier says. In other words, it detonates like a nuclear bomb and explodes outwards as a Type Ia supernova. This mass threshold is known as the Chandrasekhar limit after the Indian astrophysicist Subrahmanyan Chandrasekhar, who calculated it aged just 19 during a sea voyage to Europe in 1930. It's possible for a stable white dwarf to approach this threshold by gaining mass from somewhere else.

Frohmaier says there are two main options being considered by astrophysicists. The first, called the single-degenerate scenario, involves the white dwarf ripping gas from a companion star. This could be an ordinary star like the Sun, or a Sun-

The star Wolf-Rayet 124 is giving hints that it's due to explode soon

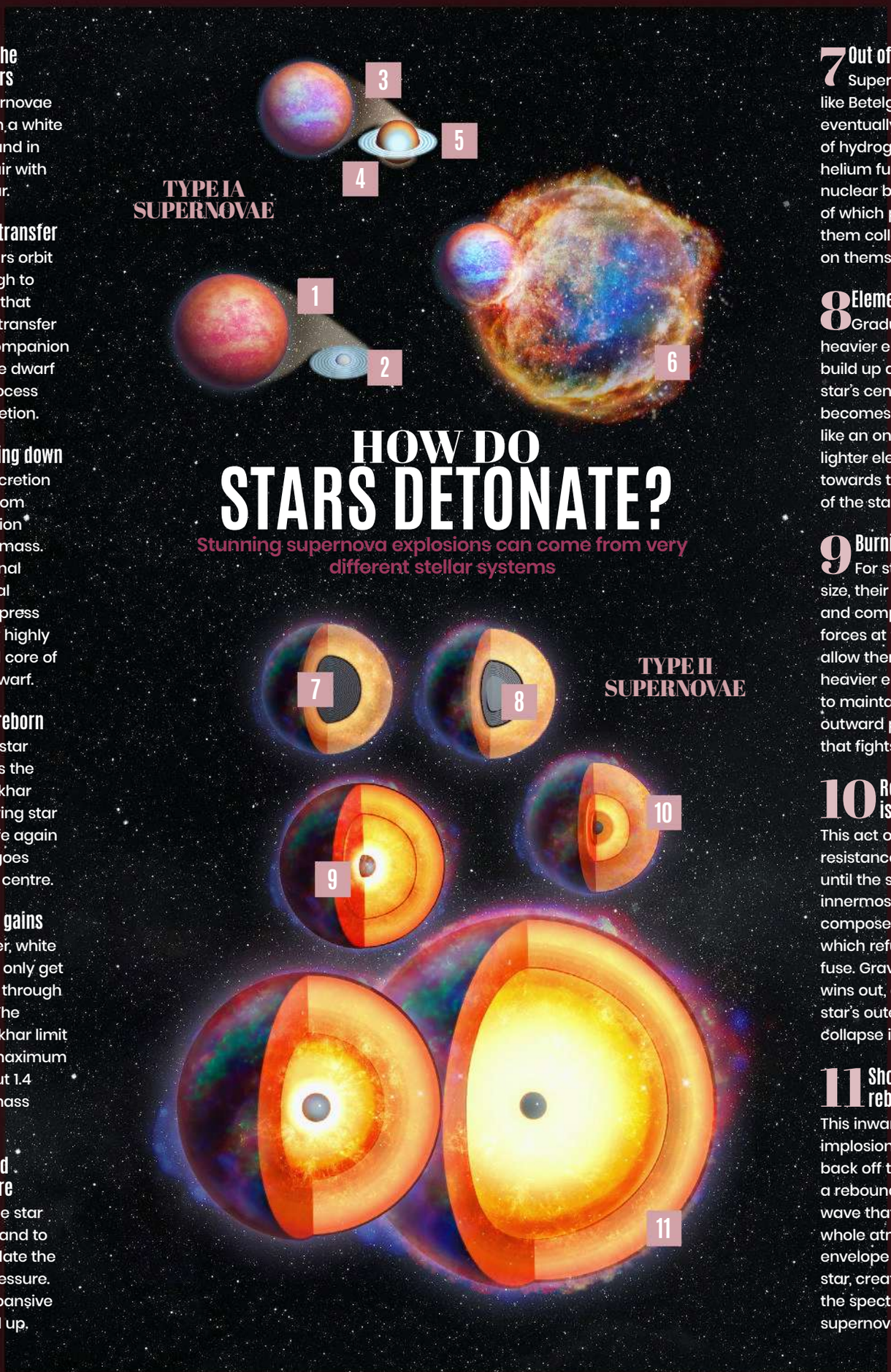


SN 1987A

Supernovae are reasonably common - about two explode every century in a galaxy like our Milky Way. With hundreds of billions of galaxies to observe, astronomers see them on a regular basis. Usually, they're far away, meaning astronomers can struggle to see them in detail. Astronomers were handed an astronomical gift in 1987 when a Type II supernova exploded in the Large Magellanic Cloud, one of the satellite galaxies of the Milky Way. At just 168,000 light years away, they could observe never-before-seen features of the explosion. It was the first time that astronomers were able to confirm that radioactive decay is responsible for the visible light we see from core-collapse supernovae, for example. SN 1987A was also pivotal in our understanding of the role that neutrinos play. Several hours before the visible light from the supernova arrived on Earth, three separate neutrino observatories pinged with neutrino detections. It confirmed predictions from theoretical models that 99 per cent of the energy of a supernova is carried away by these ghost-like subatomic particles.

HOW DO STARS DETONATE?

Stunning supernova explosions can come from very different stellar systems



1 Finding the right stars
These supernovae occur when a white dwarf is found in a binary pair with another star.

2 Matter transfer
Two stars orbit close enough to each other that matter will transfer from the companion onto a white dwarf star in a process called accretion.

3 Squeezing down
This accretion of matter from its companion adds extra mass. The additional gravitational forces compress the already highly pressurised core of the white dwarf.

4 A star reborn
As the star approaches the Chandrasekhar limit, the dying star comes to life again and undergoes fusion in its centre.

5 Limited gains
However, white dwarfs can only get so massive through accretion. The Chandrasekhar limit puts their maximum size at about 1.4 times the mass of our Sun.

6 Outward pressure
This time the star cannot expand to accommodate the outward pressure. Instead, expansive forces build up.

7 Out of gas
Supergiants like Betelgeuse will eventually run out of hydrogen and helium fuel, the nuclear burning of which prevents them collapsing in on themselves.

8 Elemental onion
Gradually, heavier elements build up at the star's centre, which becomes layered like an onion, with lighter elements towards the outside of the star.

9 Burning fuels
For stars this size, their mass and compressional forces at the core allow them to fuse heavier elements to maintain the outward pressure that fights gravity.

10 Resistance is futile
This act of resistance holds until the star's innermost core is composed of iron, which refuses to fuse. Gravity finally wins out, and the star's outer layers collapse inwards.

11 Shock wave rebound
This inward implosion bounces back off the core as a rebounding shock wave that blows the whole atmospheric envelope off the star, creating the spectacular supernova.

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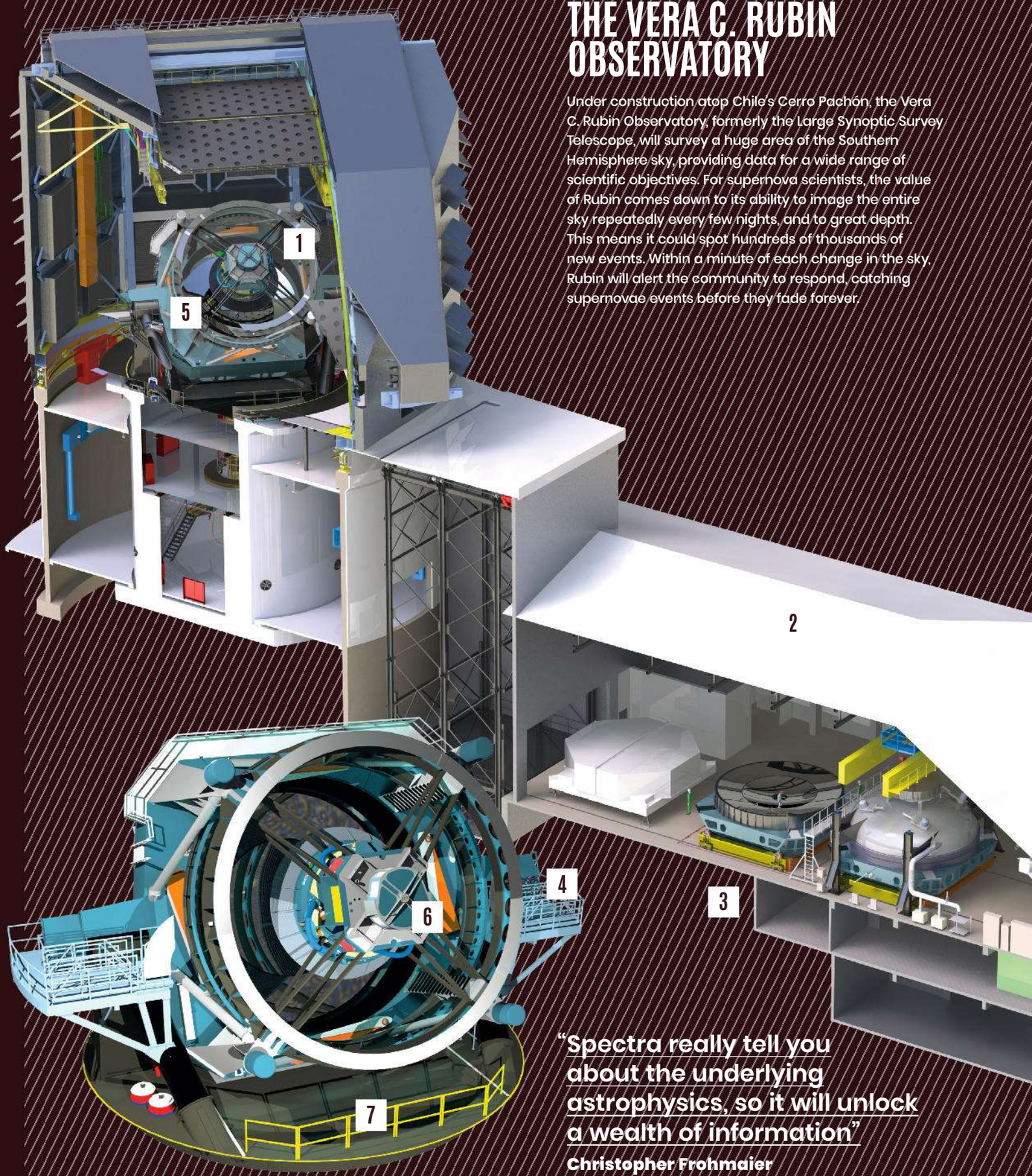
THE VERA C. RUBIN OBSERVATORY

Under construction atop Chile's Cerro Pachón, the Vera C. Rubin Observatory, formerly the Large Synoptic Survey Telescope, will survey a huge area of the Southern Hemisphere sky, providing data for a wide range of scientific objectives. For supernova scientists, the value of Rubin comes down to its ability to image the entire sky repeatedly every few nights, and to great depth. This means it could spot hundreds of thousands of new events. Within a minute of each change in the sky, Rubin will alert the community to respond, catching supernovae events before they fade forever.



"Spectra really tell you about the underlying astrophysics, so it will unlock a wealth of information"

Christopher Frohmaier

1 Large mirror
Rubin's reflecting telescope contains an 8.4-metre (28-foot) primary mirror that can track across at sufficient pace to image the entire sky every few nights.

2 Environment
The design of the observatory takes advantage of the mountain's natural topography. Its orientation was selected after extensive weather testing.

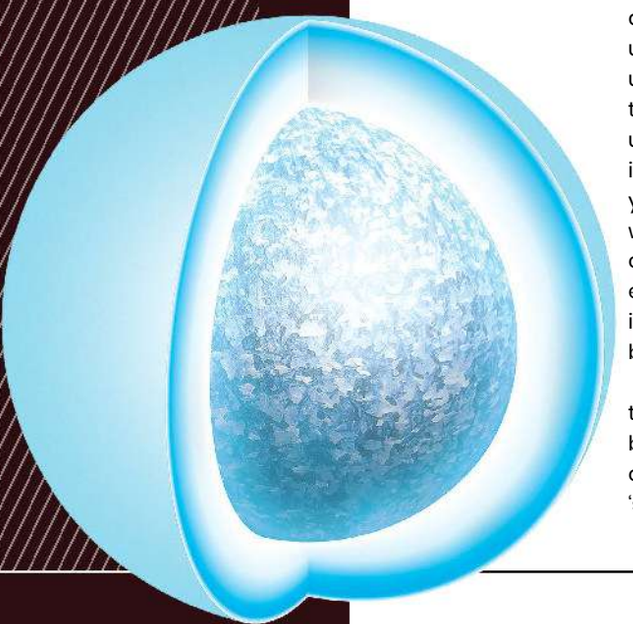
3 Keeping cool
To protect the mirror, the heated operation spaces are located below the service level. The heat-generating equipment is below that, farthest from the telescope.

4 Wide-angle lens
To maximise its potential to spot new transient phenomena, Rubin has a 3.5-degree field of view – the Sun as seen from Earth is only 0.5 degrees across.

5 Multi-band
Rubin will carry out a deep ten-year imaging survey in six broad optical bands to maximise the data provided on any supernovae or progenitors imaged.

6 On-site maintenance
The observatory has its own dedicated cleaning and coating area where the mirrors are washed and recoated during operations.

7 Big camera
Images will be recorded by a 3.2-gigapixel camera. It will take a 15-second exposure every 20 seconds to help detect new high-energy events.



A The lens of the camera that will conduct the LSST

V About the size of Earth, a white dwarf is made of carbon and oxygen

like star that's itself on the way out, having puffed up into a so-called red giant. However, the ensuing supernova would interact with some of the hydrogen of the companion star, causing it to glow. "No one has seen that hydrogen," says Frohmaier, which means that most researchers are starting to favour the so-called double-degenerate scenario instead. Picture two Sun-like stars orbiting one another in a binary system. Such a scenario is very common, as at least half of the stars in the universe are thought to exist in these binary pairs. Both stars reach the end of their lives and become white dwarfs. The two white dwarfs circle around one another, gradually spiralling inwards towards oblivion. "They collide into a single white dwarf that's too massive to exist," Frohmaier says, and in a matter of milliseconds they detonate as a Type Ia supernova.

Understanding what causes these enigmatic explosions is vital because Type I supernovae are used as cosmic rulers to measure distances in the universe. If every Type Ia supernova is the result of a detonation of a white dwarf, or dwarfs, with a total mass close to the Chandrasekhar limit, then each explosion will have a similar brightness, thus those that appear dimmer to us must be further away. In the late 1990s, astronomers used measurements of Type Ia supernovae to show that the expansion of the universe appears to be speeding up. If it continues to accelerate as it is, then all structures in the universe will be torn apart in around 22 billion years in an event astronomers call the 'Big Rip'. Exactly what's driving the quickening expansion is unclear, but cosmologists point to the influence of a mysterious entity dubbed dark energy – yet they don't know what it is or how it works. Understanding Type Ia supernovae better might provide valuable clues.

Astronomers refer to objects like Type I supernovae that have an inherently fixed brightness and can be used to measure cosmic distances as standard candles. Frohmaier prefers to call Type Ia supernovae 'standardisable candles'. "There's some variation in

© Getty; LSST

the brightness of these objects," he says. Astronomers have to make corrections for these subtle differences in order to use them as celestial rulers. "That's worked well for 20 years, but as we enter the next era of telescopes we're being held back by our lack of understanding of astrophysics."

Astronomers may not have to wait much longer for answers. Construction is almost finished on the much anticipated Vera C. Rubin Observatory in Chile, which should see the start of full operation towards the end of 2024. It's home to the largest digital camera ever constructed, with a total of 3,200 megapixels, and it's about the size of a person. This colossal camera will be at the heart of an observing run known as the Legacy Survey of Space and Time (LSST). Astronomers expect to spot hundreds of thousands of new supernovae. "It will be revolutionary for cosmology," Frohmaier says.

While this will spot supernovae, it won't be able to measure their spectra. For that astronomers will turn to another facility in Chile. The 4-metre Multi-Object Spectrograph Telescope (4MOST) is an instrument attached to the Visible and Infrared Survey Telescope for Astronomy (VISTA) at Paranal Observatory. Rather than measuring the spectrum of one supernova at a time, 4MOST will be able to observe the spectra of 2,400 supernovae simultaneously. "Spectra really tell you about the underlying astrophysics, so it will unlock a wealth of information," says Frohmaier, who was recently announced as the project's deputy project scientist. It will allow astronomers to compare models of supernova explosions built in supercomputers to real data to check if they've built a realistic model.

Perhaps astronomers will finally be able to tease apart the mysteries that surround Type Ia supernova, not only measuring distances in space more accurately, but also getting a clearer understanding of why our universe continues to expand at an ever quickening pace.

A supernova would have a devastating impact on planets and its wider solar system

Colin Stuart
Astronomer and space science writer
Colin holds a degree in astrophysics, has written over 17 books on space and has an asteroid named in his honour.

FIVE STARS READY TO EXPLODE

Betelgeuse
Stellar evolution models suggest it should go supernova anytime in the next 100,000 years, when it will be as bright as the full Moon in the night sky. Even before its recent dimming, Betelgeuse showed the most variation of any progenitors.

Antares
The red eye of the scorpion in the constellation of Scorpius is due to go supernova in the next million years. With a mass 15 to 18 times that of our Sun, it will be spectacular, though its lack of variability suggests it's not quite ready yet.

Mu Cephei
Known as 'Herschel's Garnet Star', it's further away than Betelgeuse, but double its diameter, and therefore perhaps closer to death. Its supernova would likely produce a black hole while providing a 'guest star' as bright as Venus.

Eta Carinae
Observers have already seen this binary star throw out its outermost layers in a series of pulses. Much further away than Betelgeuse, its impending death could produce a gamma-ray burst or a superluminous supernova, easily visible from Earth.

V Sagittae
Made up of an ordinary star spiralling in towards a white dwarf, researchers have predicted a date later in this century for a supernova event that will create a 'new star' as bright as Sirius in the night sky.

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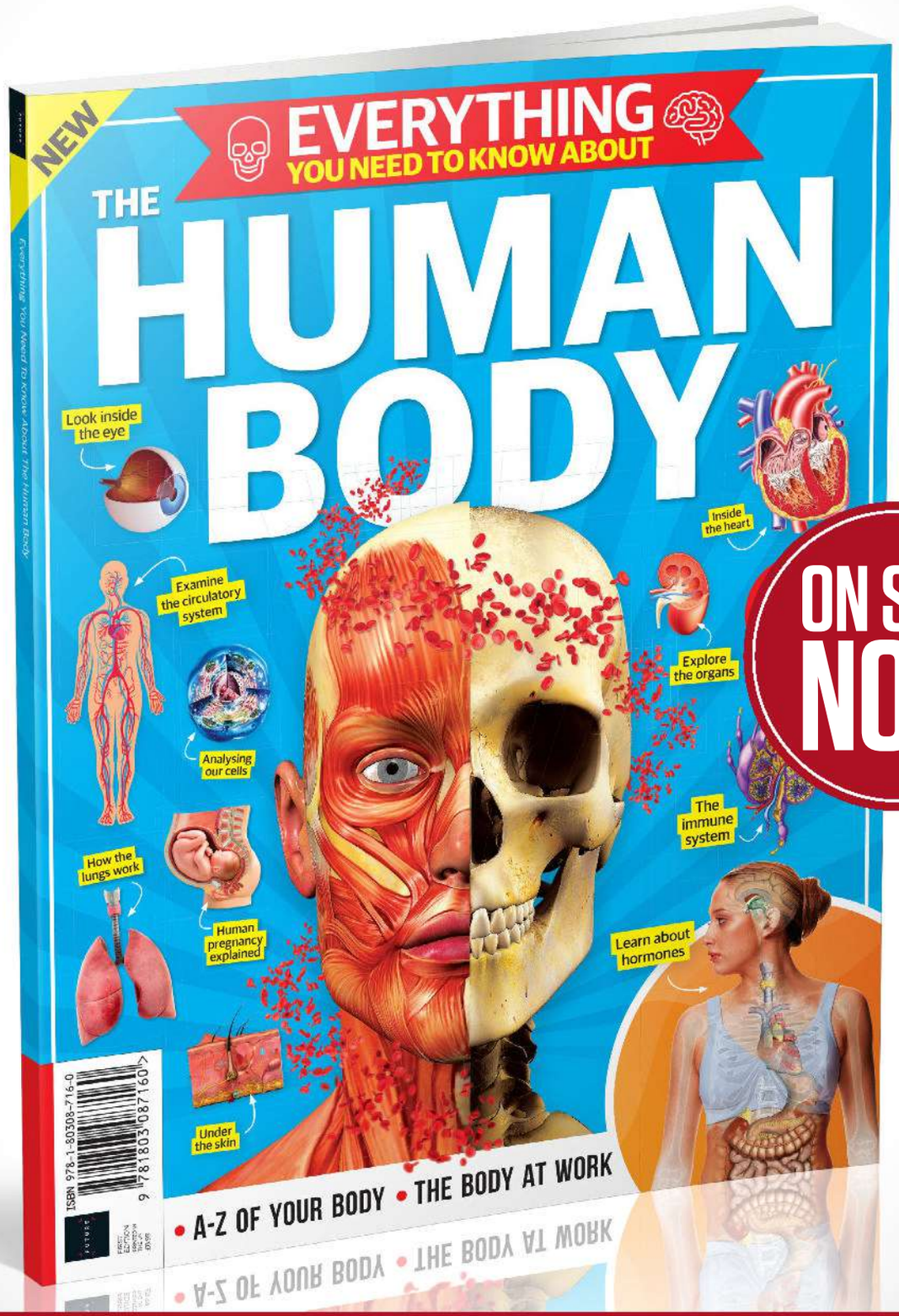

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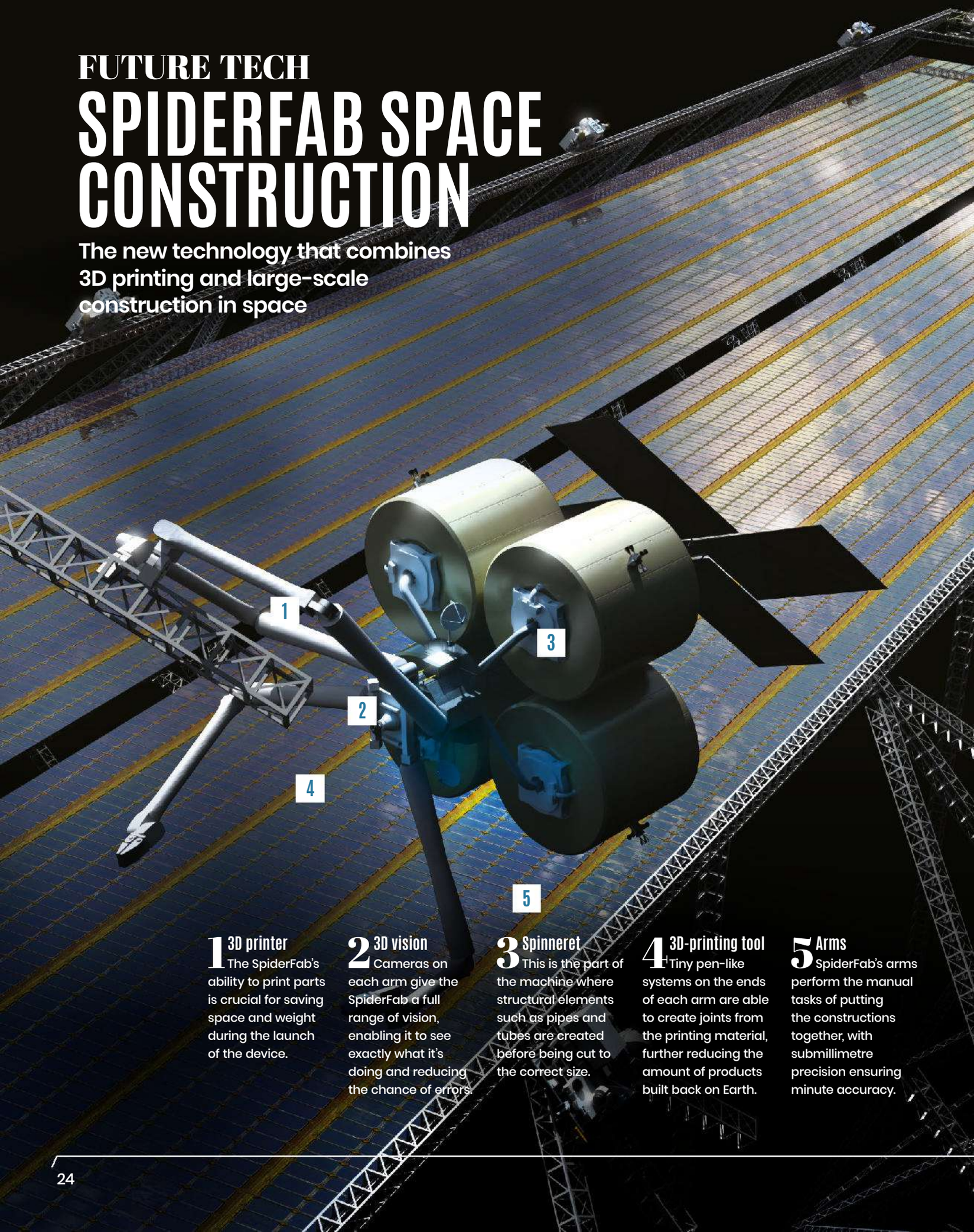
SPIDERFAB SPACE CONSTRUCTION

The new technology that combines 3D printing and large-scale construction in space



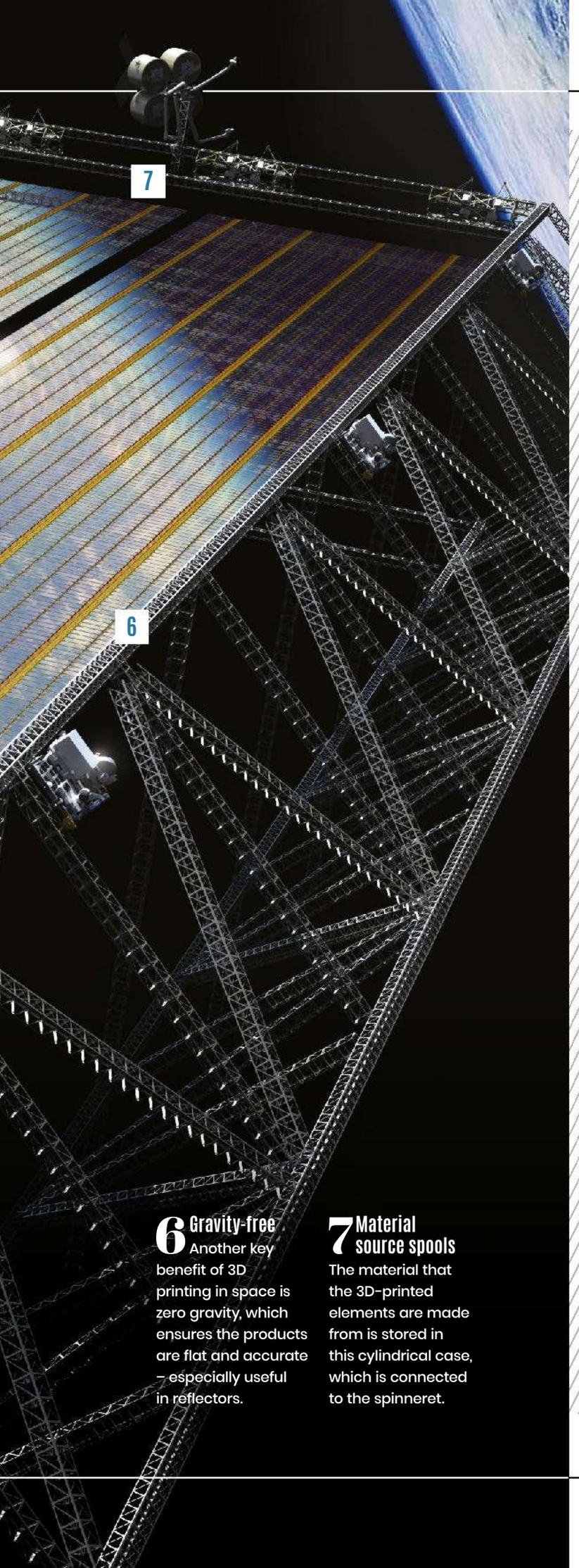
1 3D printer
The SpiderFab's ability to print parts is crucial for saving space and weight during the launch of the device.

2 3D vision
Cameras on each arm give the SpiderFab a full range of vision, enabling it to see exactly what it's doing and reducing the chance of errors.

3 Spinneret
This is the part of the machine where structural elements such as pipes and tubes are created before being cut to the correct size.

4 3D-printing tool
Tiny pen-like systems on the ends of each arm are able to create joints from the printing material, further reducing the amount of products built back on Earth.

5 Arms
SpiderFab's arms perform the manual tasks of putting the constructions together, with submillimetre precision ensuring minute accuracy.



6 Gravity-free
Another key benefit of 3D printing in space is zero gravity, which ensures the products are flat and accurate – especially useful in reflectors.

7 Material source spools
The material that the 3D-printed elements are made from is stored in this cylindrical case, which is connected to the spinneret.

If you think putting together a wardrobe is tough, you should see one of the technologies that's received the green light from NASA's Institute of Advanced Concepts (NIAC). SpiderFab is a creation from Tethers Unlimited that will build structures in space, slashing the cost and difficulty of launching mission devices. At the moment, structures have to be put together on Earth before being launched into space. This requires a large and powerful rocket, increasing both the cost and difficulty of the mission.

The idea behind SpiderFab is to have all the individual components stored in the payload. Once a smaller, more efficient rocket has delivered them safely into space, it will get to work constructing the device. A starshade is a large screen placed in front of a space telescope that enables it to photograph the exoplanets of far-away stars, so the benefits of constructing this sort of equipment using SpiderFab are plain to see. By sending a starshade up in pieces to be put together in space, efficient packing would enable the construction to be twice the size, exactly the same mass and an incredible 1/30th of the volume, halving the mission cost.

The 3D-printing element is a key aspect of the SpiderFab's appeal. It can construct elements such as carbon-fibre tubes seemingly from nowhere, once again saving hugely on the space used and the cost of sending prebuilt tubes into space. It can also 3D print joints, meaning that it only needs to be sent up with the bare minimum of prebuilt objects and the materials to 3D print the rest. It's accurate to submillimetre levels, so scientists should have few concerns about accuracy.

SpiderFab is aptly named as its appearance is much like a spider, with a number of limbs that it uses to assemble the structure along with a 3D vision system to enable it to detect what it's doing. Another amazing thing about the device is its sheer range of abilities. Not only does it have the handyman skills to construct a device in outer space, but SpiderFab can create many useful space products, such as parabolic reflectors, optical mirrors, solar arrays and phased array antennae. Far from being a one-trick pony, SpiderFab could be the solution to sending products into space far more easily and cheaply.

With this newfound flexibility, scientists could learn more about the universe, sending up more missions due to the reduced cost. They could also push the boundaries of what we previously thought was possible once SpiderFab has made bigger, better and more accurate astral constructions a real possibility. We could gaze further, in greater detail and perhaps even travel vaster distances, all thanks to one small, multi-limbed 3D-printing robot.

"SpiderFab could be the solution to sending products into space"

© Adrian Mann

BIO+

Tim Dodd

Dodd is the man behind the internet-streamed show *Everyday Astronaut*, dedicated to bringing space down to Earth for everyday people. Born in 1985, Dodd and his team provide video updates on space and captivating interviews with leading rocketeers, including Elon Musk and the SpaceX Starship program. Dodd transitioned from a professional photographer to start *Everyday Astronaut* in 2014 as an art project on Instagram, and in 2017 he took to YouTube, posting videos produced to enthral and educate the public about spaceflight.

The Everyday Astronaut

"It's okay to get really technical with people"

The Everyday Astronaut turns out to be a not-so-everyday kind of person. Here he reveals his one on ones with Elon Musk and how he brings space down to Earth for everyday people

Interviewed by Leonard David

It seems like your passion for space evolved rapidly. How did your show come to be?
I'm a bit of a college dropout and ended up being a professional photographer for eight years or so. I've always liked mechanical things and enjoyed working on cars and motorcycles growing up. My dad was an engineer, so I always had my hands dirty, building and fixing things. I got really interested in turbochargers and performance cars that had turbochargers. I like things that go fast, and nothing goes faster than a rocket. It's kind of the ultimate version of horsepower and power. It was a photo assignment to shoot the SpaceX CRS-3 [Commercial Resupply Service mission] that got me up close and personal to the hardware. It kind of hit me across the face. I was inspired and excited.

Is there a message in your show that you want audiences to appreciate?
I think people get excited about things when they are educated about things, when they get their questions answered. And that's when they get their curiosity going. That little light bulb goes off in their head. I'm still learning as fast as I possibly can each day. I still feel like I have a million things to learn.

Just how technical can you be for your audience?
What I've found is that it's okay to get really technical with people. My audience loves that. They love when I dive in deep. Appreciating some of the small details can lead to even bigger questions – more technical questions. The trick is that you've got to make a story out of it.

Your one on ones with Elon Musk were greatly received.
I think he really likes being asked technical questions. He's a very technical guy and has an incredible breadth of knowledge. He knows an insane amount about a lot of things. I think he just appreciated someone else that could hang with him and not just ask the same ten questions.

You've had the opportunity to talk to leading space entrepreneurs. What's your view of them?
There's a disconnect in the general public regarding the 'why' of space. They think why are billionaires wasting their money with fanciful space stuff? They don't understand that our daily lives revolve around these space assets and that our lives improve. The cheaper we can get things into space, and eventually get more and more things down from space, the quality of life will keep going up for the average person on Earth. There's a disconnect between the point of this getting cheaper, more routine and more

readily available and what that means for the average person here on Earth, the lifestyles that it can advance.

When you talk with space entrepreneurs, do you sense any common thread between them and how they run their companies?
The people I talk to are full-blown rocket nerds. They know their vehicles inside and out. There's a level of depth they have in operating these companies. They are hands-on with the engineers and engineering. They are there on the factory floor every day looking at hardware. They are not just some face or some people manager – they have to do all of it. You have to be at that level. That might be the difference between the ones that fail and the ones that succeed. They understand their system as a whole.

There are consequences in using space, be it space debris or megaconstellations upsetting the astronomical community. What's your take on these issues?
It's a wild Wild West version of outer space at this point. Space debris is definitely something we have to be considering. We are starting to get some of that legislation, to make sure that there are protocols on life spans of satellites. It's a real, genuine concern. If we don't start to get a handle on things like every single satellite having an end-of-service deorbit plan and controlled avoidance manoeuvring, we're setting ourselves up for a disaster.

Then there are the megaconstellations that are blinding ground astronomers...
It's kind of one of those awkward things. I think the solution to better astronomy in the future is all space-based assets. If we can start launching things at a tenth or a hundredth the price today, the space telescopes we can have will make the James Webb Space Telescope look like a joke. We get through our cruddy atmosphere much better than we can today. But unfortunately there are a couple of decades of this awkward overlap, having space assets interfere with astronomy. But it will cross back over when space astronomy is clearly superior over ground-based astronomy, so it's an overall win.

Where do you see *Everyday Astronaut* headed?
Honestly, I wore myself out trying to do on-site live streaming. I'm such a perfectionist. I want things to be good enough quality that it justifies me being there. I love making deep-dive videos, and even more fun for me are topics that are less topical, like why don't rocket engines melt? How do you power a rocket engine? How do you start a rocket engine? By the way, starting a rocket engine is the hardest thing of all. Running and operating a rocket engine is relatively easy. But getting it started is very difficult!

Hopefully my audience will crave more and dive into more niche and in-depth videos. My goal is to find people and spark their interest, even those that didn't know they were interested in or loved spaceflight.

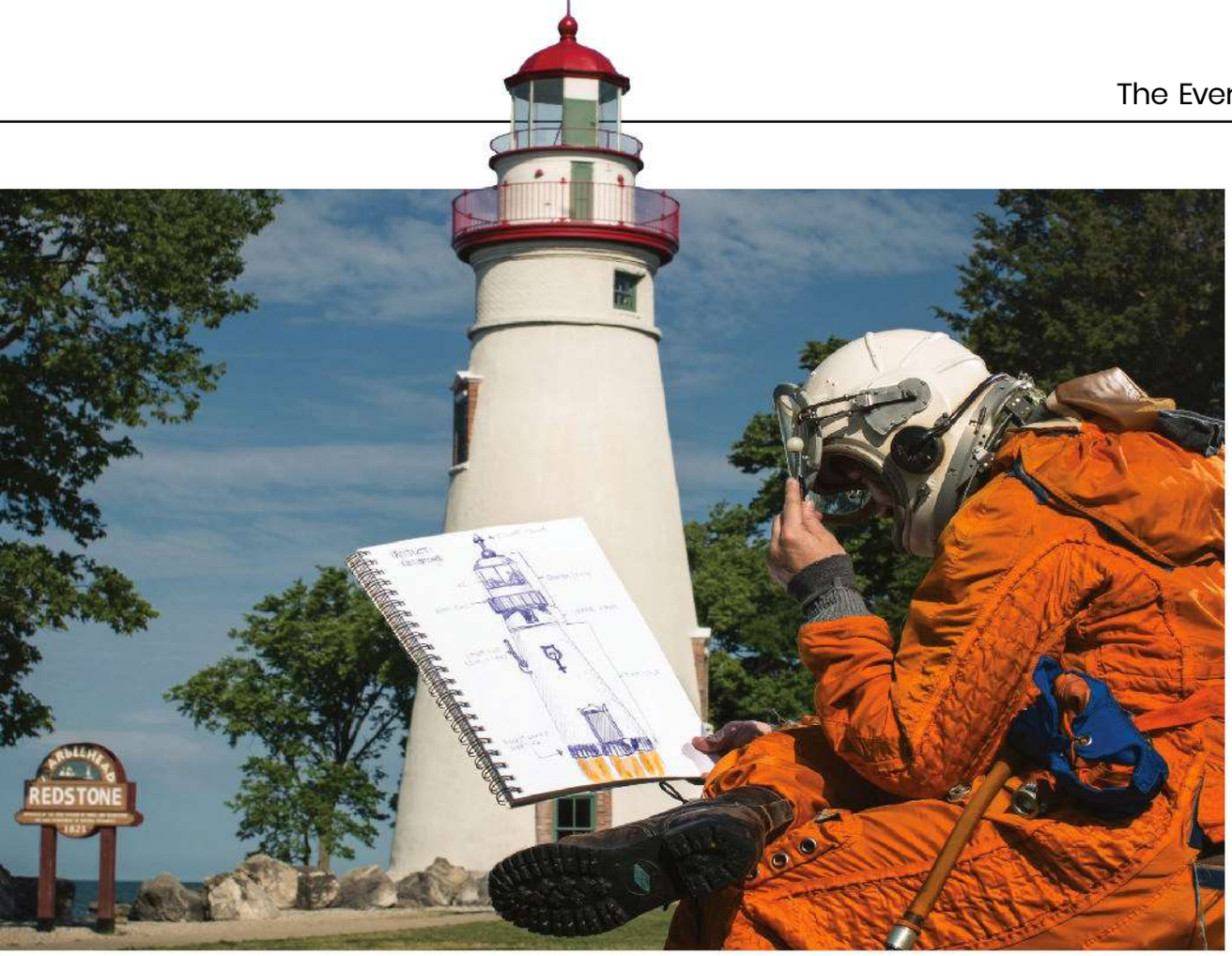
There are those wincing about NASA versus commercial space organisations, such as the viability of the agency's Space Launch System (SLS) contrasted to SpaceX abilities. What's your opinion?
First off, I'm so glad the first SLS and Orion was a huge success. I do think it's an important backbone to ensure there's momentum. It's a pretty big cost, but I still think that it's worth it, and it's currently the only proven thing capable of getting humans to the Moon. I think that there's a bit of an awkward growing phase here – awkward timing in the grand scheme of things – but I'm excited to see this transition to make a switch over to other systems that are capable. But in the meantime, we have SLS and a capability, so use it.

Of course, the big news is your selection for the dearMoon flight on Starship. What happens now, and are you prepared for your own liftoff?
Seriously, I'm realising that I need to make sure I'm staying in shape. The last six months of chasing live streams means eating a lot of fast food, sleeping poorly and cramming food in when there's five minutes to spare. I'm focusing on that now.

How about training for the flight?
I don't have exact timelines on that yet.

"The people I talk to are full-blown rocket nerds. They know their vehicles inside and out"

Dodd takes his viewers behind the scenes of space exploration



Dodd utilises his photography skills in his work for *Everyday Astronaut*

Dodd mixes the technical stuff with fun

So much of it depends on Starship. We're all waiting anxiously for the first orbital tests to happen. At this point, we're kind of on standby, ready to dive in on training aspects when we get the go-ahead. In looking at earlier citizen training for orbital missions, that's around six months, so probably something similar to that. Orbital missions have more risk, they're a lot more involved and there's more missions. I think each of us has to be familiar with the spacecraft, our mission, what to expect and what tasks are at hand.

And you're taking a week-long journey to the Moon!
We're going to be the first civilians to orbit the Moon and likely some of the first humans to go since the Apollo astronauts. I don't know if we're going to be first. There's a good chance that Artemis II may beat us. But we're going to be on that short list of people in the 21st century to visit the Moon and see the Moon with our own eyes, up close. The dearMoon project is making sure we're a cohesive team. They had over a million applicants, and they whittled it down to the eight of us. I'm working alongside people that are so talented. It's really going to be something special. Our mission is to absorb this flight and communicate it back home.

Of the eight individuals on board, I would think you know more about the ins and outs of how Starship ticks. Will that be unnerving on launch day?
Obviously, the whole spectrum, from failure to success, is always in my head. Frankly, it's going to take some convincing for it to become a reality and to have that confidence. So far, it's an iterative phase of the vehicle. I'm confident that they'll have the right solution to getting the vehicle safe for human spaceflight. But I'm also confident that they are going to do a lot more certifications and have people reaffirm me about the whys and hows – how they're going to keep us safe.

We're not signed up for a deathbed here. We're signed up for a citizen spaceflight. We're expecting it to be commercial and safe. I expect no less.

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FOCUS ON

A RADIO TELESCOPE ON THE MOON'S FAR SIDE WILL PEER INTO THE UNIVERSE'S 'DARK AGES'

The LuSEE-Night pathfinder is scheduled to launch a few years from now

Reported by Josh Dinner

A small radio telescope on the far side of the Moon could help scientists peer into the universe's ancient past. The Lunar Surface Electromagnetics Experiment-Night (LuSEE-Night) is a pathfinder being developed by the US Department of Energy's Brookhaven and Lawrence Berkeley National Laboratories, the Space Science Laboratory at the University of California, Berkeley and NASA's Science Mission Directorate.

LuSEE-Night is scheduled to launch on a private lunar lander in late 2025. After it touches down on the Moon's far side, it will attempt to gather first-of-their-kind measurements from the Dark Ages of the universe. This refers to a time in the early universe before stars and galaxies began to fully form. From the far side of the Moon, LuSEE-Night will use onboard antennae, radio receivers and a spectrometer to measure faint radio waves from the Dark Ages in search of what scientists are calling the Dark Ages signal.

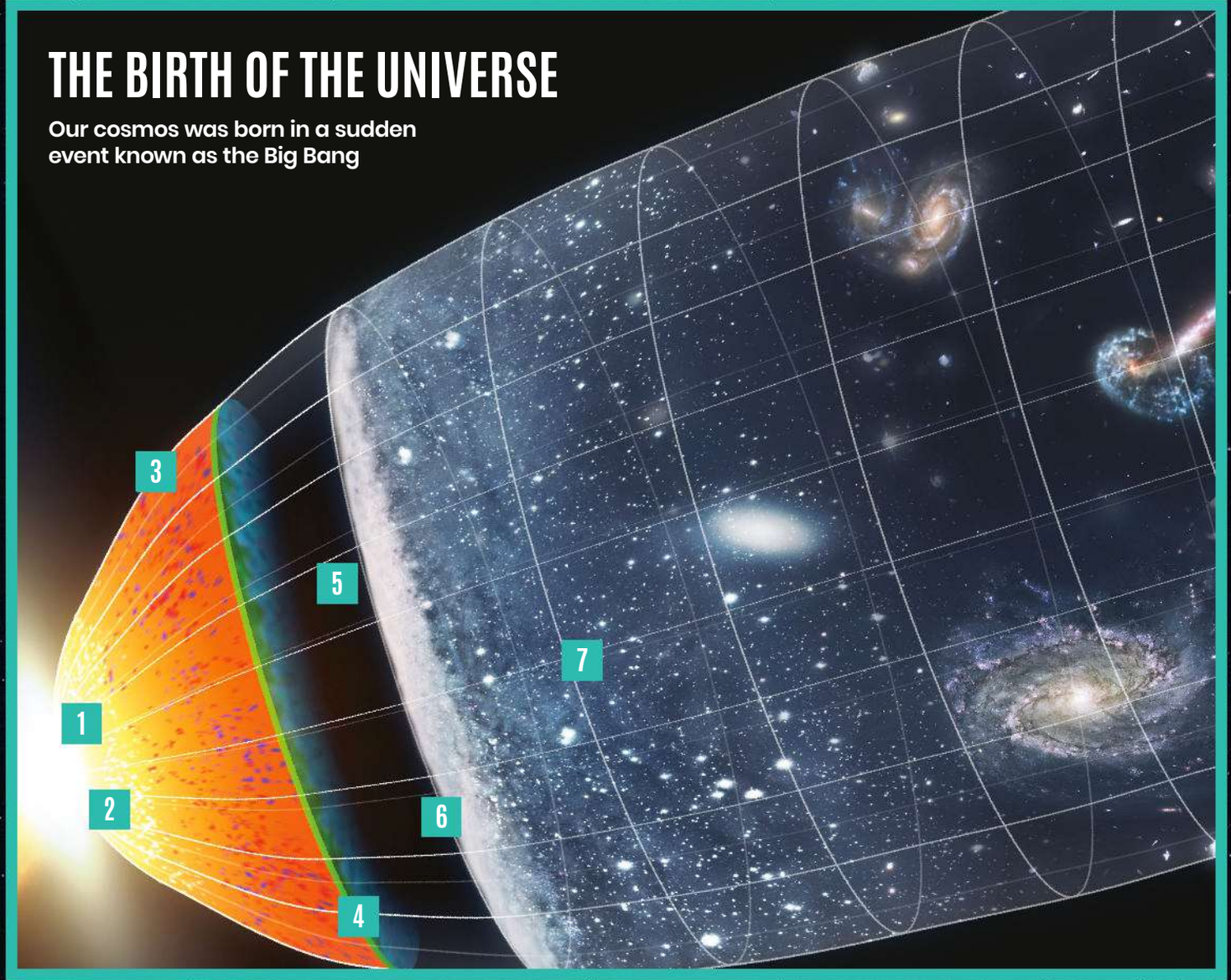
"So far, we can only make predictions about earlier stages of the universe using a benchmark called the cosmic microwave background. The Dark Ages signal would provide a new benchmark," Brookhaven physicist Anže Slosar said. "And if predictions based on each benchmark don't match, that means we've discovered new physics." LuSEE-Night isn't expected to make such big breakthroughs all by itself – it's a pathfinder designed to pave the way for more ambitious instruments down the road. The larger project could end up shedding light on such big cosmic questions as the nature of dark energy and the creation of the universe.

The far side of the Moon is a great place to look for the faint signals that could hold such clues because it offers something Earth cannot: a deep and profound silence. Constant radio bombardment across our planet creates an environment too noisy for the supersensitive instruments LuSEE-Night will use. However, the faraway locale presents challenges as well. Surviving there takes a feat of engineering. Though sometimes mislabelled the 'dark side' of the Moon, the part of Earth's natural satellite that faces away from us in the night sky does in fact have a day-night cycle, each phase of which lasts about 14 Earth days. Temperatures on the far side of the Moon fluctuate between around 121 and -173 degrees Celsius (250 and -280 degrees Fahrenheit), so LuSEE-Night will have to be designed to withstand two weeks of intensely unforgiving non-stop lunar day Sun, as well as remain powered through

As the Moon is tidally locked to Earth, one side is hidden from us

THE BIRTH OF THE UNIVERSE

Our cosmos was born in a sudden event known as the Big Bang



two weeks of cold darkness – and do this over and over again. The mission design lifetime on the lunar surface is two years.

"In addition to the significant potential science return, demonstration of LuSEE-Night's lunar night survival technology is critical to performing long-term high-priority science investigations from the lunar surface," said Joel Kearns, deputy associate administrator for exploration in NASA's Science Mission Directorate. When it's ready, LuSEE-Night will launch on a future commercial lunar payload services mission, an initiative from NASA that allows rapid acquisition of lunar delivery services from American companies for payloads that advance capabilities for science, exploration or commercial development of the Moon.

1 Big Bang
Around 13.8 billion years ago and in an infinitely dense moment, the universe was born from a singularity.

2 Event horizon
A boundary in space-time, beyond which events cannot affect an outside observer.

3 Inflation
A mysterious particle or force accelerated the expansion of the universe.

4 CMB
After 380,000 years, the universe became transparent to light and the CMB began to shine.

5 Dark Ages
Clouds of dark hydrogen gas cooled down and combined.

6 First stars
Gas clouds collapsed and the fusion of stars began.

7 Galaxies
Gravity caused the first galaxies to form, merge and drift.

© Getty Images

Bluffer's guide to ROCKET SCIENCE

Rockets of all kinds are still our only way of reaching space – but just how do they work?

Written by Giles Sparrow

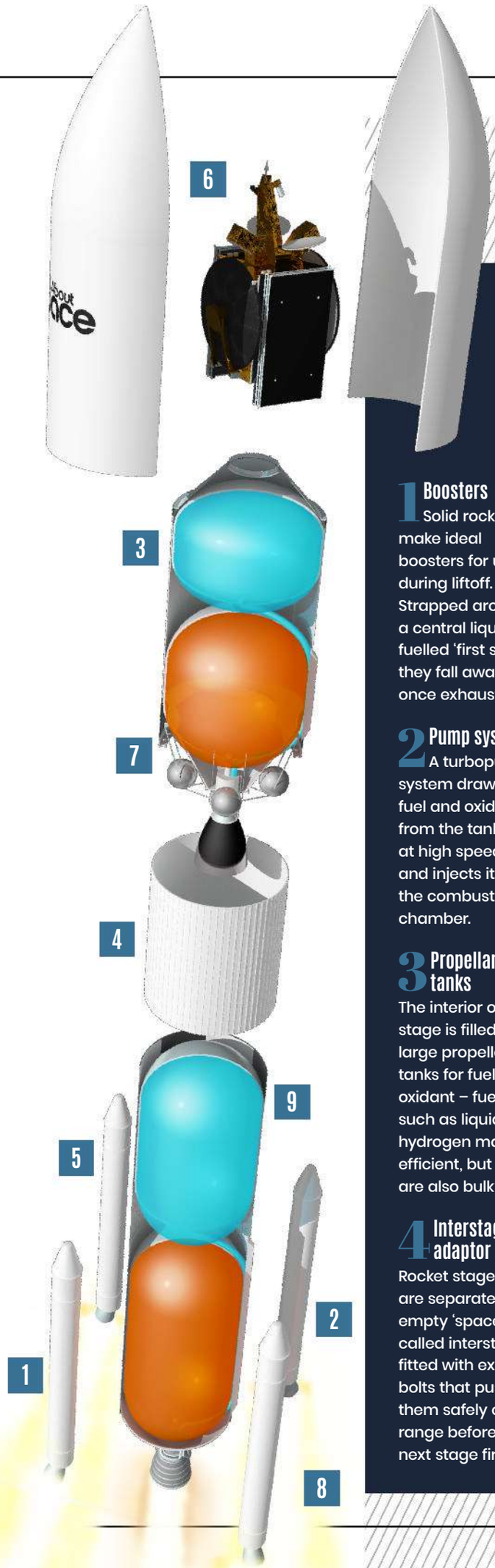
HOW A ROCKET'S MOTORS WORK

Rocket engines are complex machines that must endure ferocious heat and pressure

Modern rocket motors have come a long way from fireworks. Relatively simple solid rockets, most often used as boosters to provide extra thrust at launch, still rely on the same basic principle of igniting a tube containing a combustible mix of fuel and oxidant. Once ignited, a solid rocket will burn until its fuel is exhausted, but the rate at which fuel is burnt – and thus the amount of thrust – can be controlled by changing the amount of surface exposed to ignition during different times in the rocket's flight by packing the fuel-oxidant mix with a hollow gap down the centre, running along the length of the rocket. Depending on the profile of this gap, which may be circular or star-shaped, for instance, the amount of exposed surface will change during the flight.

The more widespread liquid-fuelled rockets are far more complex. Typically, they involve a pair of propellant tanks – one each for the fuel and the oxidant – connected to a combustion chamber through a complex maze of pipes. High-speed turbopumps driven by their own independent motor systems are used to deliver liquid propellant into the chamber through an injection system. The rate of supply can be throttled up or down depending on requirement, and fuel can be injected as a simple jet or a fine spray. Inside the combustion chamber, an ignition mechanism is used to begin combustion – this may be a jet of high-temperature gas, an electric spark or a pyrotechnic explosion. Rapid ignition is critical – if too much fuel-oxidant mixture is allowed to build up in the combustion chamber, then a delayed ignition can generate enough pressure to blow the rocket apart, a catastrophic event that rocket engineers refer to as a 'hard start' or 'rapid unscheduled disassembly'.

The detailed design of a liquid rocket stage can vary a lot depending on its fuel and other requirements. Some of the most efficient propellants are liquefied gases such as liquid hydrogen, which is only stable at very low temperatures of around -253 degrees Celsius (-423 degrees Fahrenheit). Once loaded aboard the rocket, these 'cryogenic' propellants must be stored in heavily insulated tanks. Some rockets avoid the need for an ignition mechanism using 'hypergolic' propellants that ignite spontaneously on contact.



1 Boosters
Solid rockets make ideal boosters for use during liftoff. Strapped around a central liquid-fuelled 'first stage', they fall away once exhausted.

2 Pump system
A turbopump system draws fuel and oxidant from the tanks at high speed and injects it into the combustion chamber.

3 Propellant tanks
The interior of each stage is filled with large propellant tanks for fuel and oxidant – fuels such as liquid hydrogen may be efficient, but they are also bulky.

4 Interstage adaptor
Rocket stages are separated by empty 'spacers' called interstages, fitted with explosive bolts that push them safely out of range before the next stage fires.

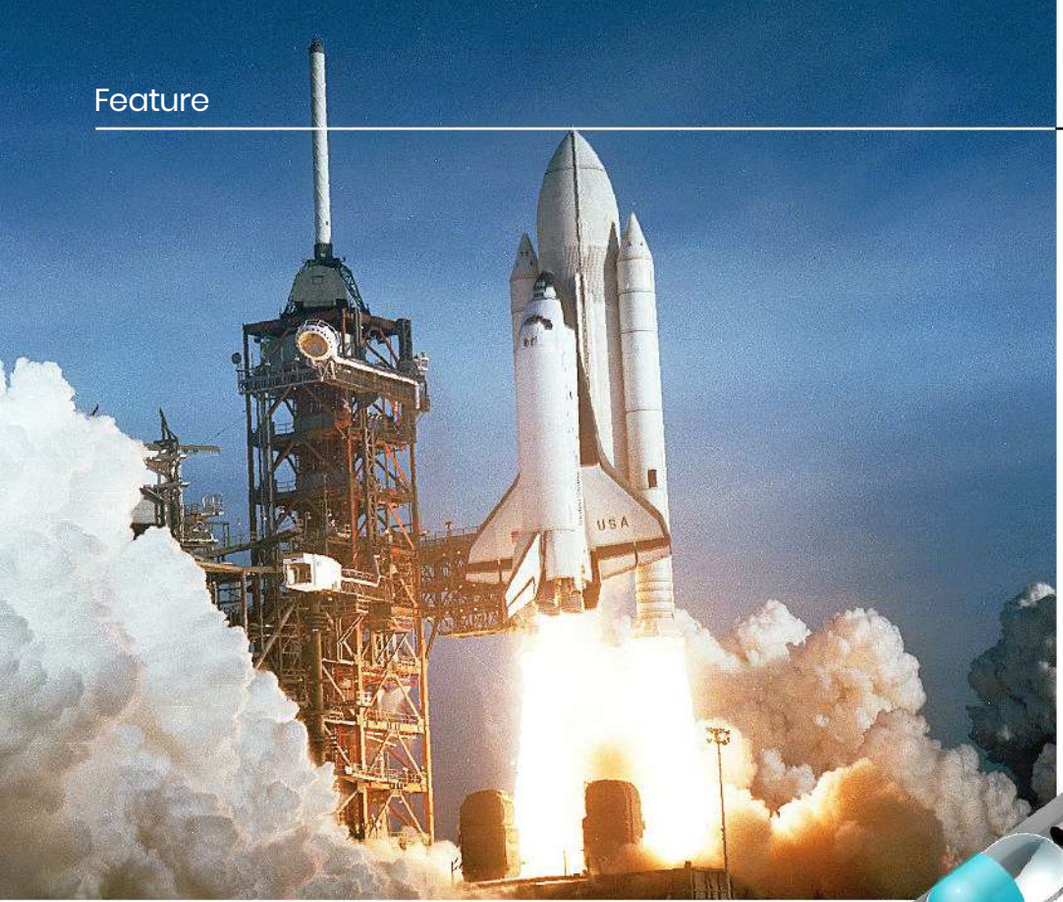
5 Ignition system
An electric spark, explosive charge or jet of hot gas ignites the fuel-oxidant mix.

6 Payload fairing
An aerodynamic case called a fairing protects the mission payload from the atmosphere during launch, then falls away in space.

7 Upper stage
Upper-stage rockets are smaller but often more complex than the lower stages, with the ability to be switched off and re-ignited at different times.

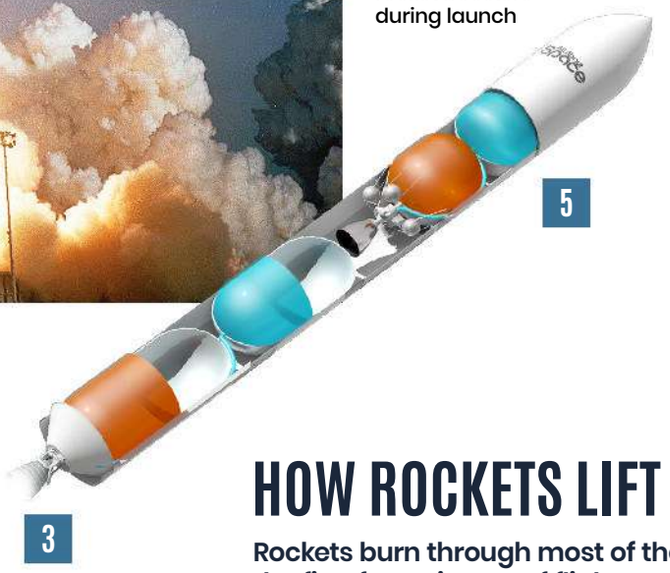
8 Combustion chamber
Fuel and oxidant undergo violent combustion, creating expanding gases that are forced out through a shaped nozzle at the bottom. This generates upward thrust in the rocket motor itself.

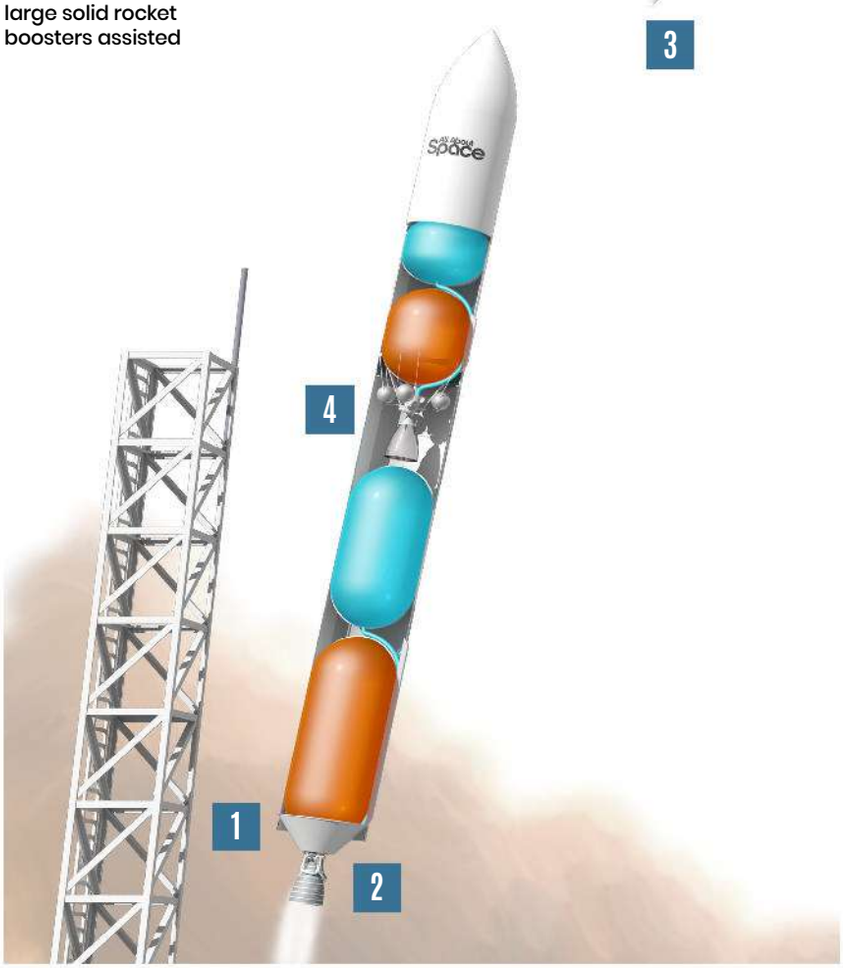
9 Solid rockets
Solid rockets have a simpler design, with a mix of fuel and oxidant that ignites when triggered and burns continuously until exhausted.



The Space Shuttle's unique design channelled propellant from an external tank to the main engines during launch, while two large solid rocket boosters assisted

The Delta II rocket's first-stage core was assisted by nine separate solid rocket boosters during launch



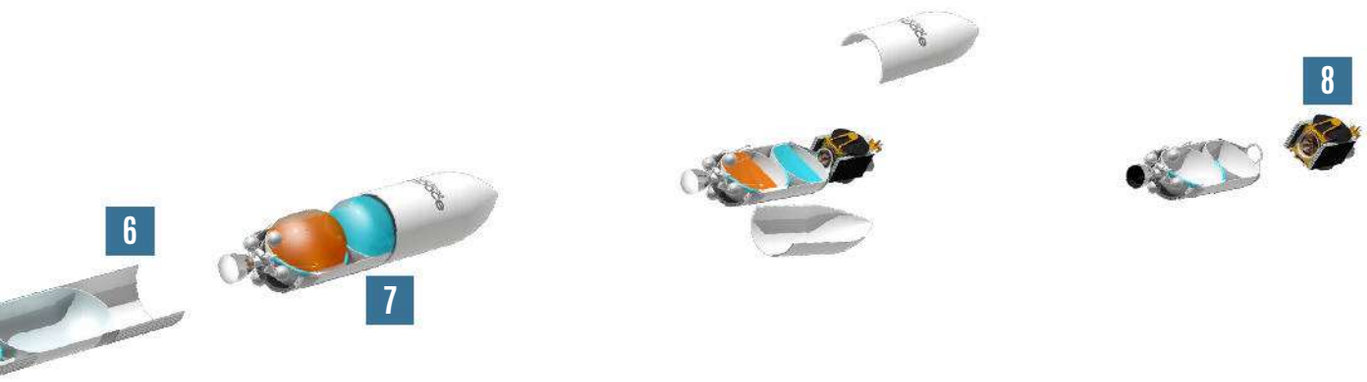


HOW ROCKETS LIFT OFF

Rockets burn through most of their fuel in the first few minutes of flight as they battle against Earth's gravity

Writers and inventors have dreamt of exploring the universe beyond Earth for centuries, but the real challenges of travelling into space only became clear in the 19th century. Experimental balloon flights showed that Earth's atmosphere thins out rapidly at high altitudes, and so even before powered flight became a reality, engineers knew that wings, propellers and other devices that create a forward or upward force by pushing against a surrounding medium like air would be no use in space. Another problem was that combustion engines – machines such as steam and petrol engines that generate power by burning fuel in the oxygen from Earth's atmosphere in a chemical reaction called combustion – would also fail in airless space.

Fortunately, a device that solved the problem of generating force without a surrounding medium had already been invented – the rocket. Initially used as weapons of war or in fireworks, rockets generate a force in one direction, called thrust, by the principle of action and reaction – exhaust fumes released by explosive chemicals are pushed out of the back of the rocket at high speed, and as a result the rocket is pushed in the other direction, regardless of any surrounding medium. The key to using rockets in space is simply to carry another chemical called an 'oxidant' that can perform the same role as the oxygen in Earth's air and allows the fuel to combust.



The first person to seriously study the rocket's potential for space travel, a Russian schoolteacher and amateur scientist called Konstantin Tsiolkovsky, first published his conclusions in 1903. He correctly identified the moment of launch as one of the biggest challenges – the moment where the rocket has to carry all the fuel and oxidant it needs to reach space – as its weight is at a maximum and a huge amount of thrust is needed simply to get it moving at all. As the rocket gets underway, it sheds mass through its exhaust. Its weight is reduced, and the same amount of thrust will have a greater effect in terms of accelerating the rest of the rocket. Tsiolkovsky came up with various rocket designs and concluded that the most efficient set-up was a vertically launched vehicle with several 'stages' – each a self-contained rocket that could carry the stages above it for a certain distance before exhausting its fuel, detaching and falling away. This principle, still widely used today, reduces the amount of 'dead weight' that needs to be carried all the way into space.

Tsiolkovsky devised a complex equation that revealed the necessary thrust force needed for any given rocket manoeuvre and the 'specific impulse' – how much thrust is generated per unit of fuel – needed for a rocket to reach space. He realised that the explosive rocket propellants of his time were far too inefficient to power a space rocket, and argued that liquid fuels and oxidants would ultimately be needed to reach orbit and beyond. Although he didn't live to see his work recognised, Tsiolkovsky's principles still underpin all of modern rocketry.

SpaceX's huge Falcon Heavy has a first-stage 'core' Falcon 9 rocket flanked by two twin Falcon 9 rockets that act as boosters during launch

"Rockets generate a force in one direction, called thrust, by the principle of action and reaction"

1 Gravity
The force of gravity pulls everything towards the centre of the Earth, exerting a downward force of 9.8 newtons per kilogram on every part of the rocket.

2 Drag
Earth's air might be thin, but it can exert a strong resistance called drag against an object moving at high speed. Fortunately, this reduces as the air becomes thin at higher altitudes.

3 Thrust
The rocket generates an upward force called thrust to overcome both gravity and drag. It does this by burning fuel and expelling exhaust gases in a downward direction that pushes the rocket upward.

4 Slow start
At launch a rocket's weight is at its greatest. Even with the rockets producing maximum thrust, they produce barely enough power to lift the rocket off the ground.

5 Rocket stages
Most rockets are designed with two or more stacked units called stages. The lowermost stage fires its engines until they are exhausted, then separates and falls away to reduce the overall mass being carried further towards space.

6 Changing altitude
As the rocket gains speed and altitude, it slowly tilts onto a path parallel with Earth's surface – this will become an orbit if it gains enough speed.

7 Shedding mass
As the rocket continues to burn fuel, its weight reduces, so although the thrust force from its engines remains constant, it has a greater accelerating effect.

8 Payload
The uppermost stage of the launch vehicle, delivered into orbit, is known as the payload. This may consist of a satellite or spacecraft, often with a separate rocket stage for further manoeuvres.

INTERPLANETARY TRAVEL

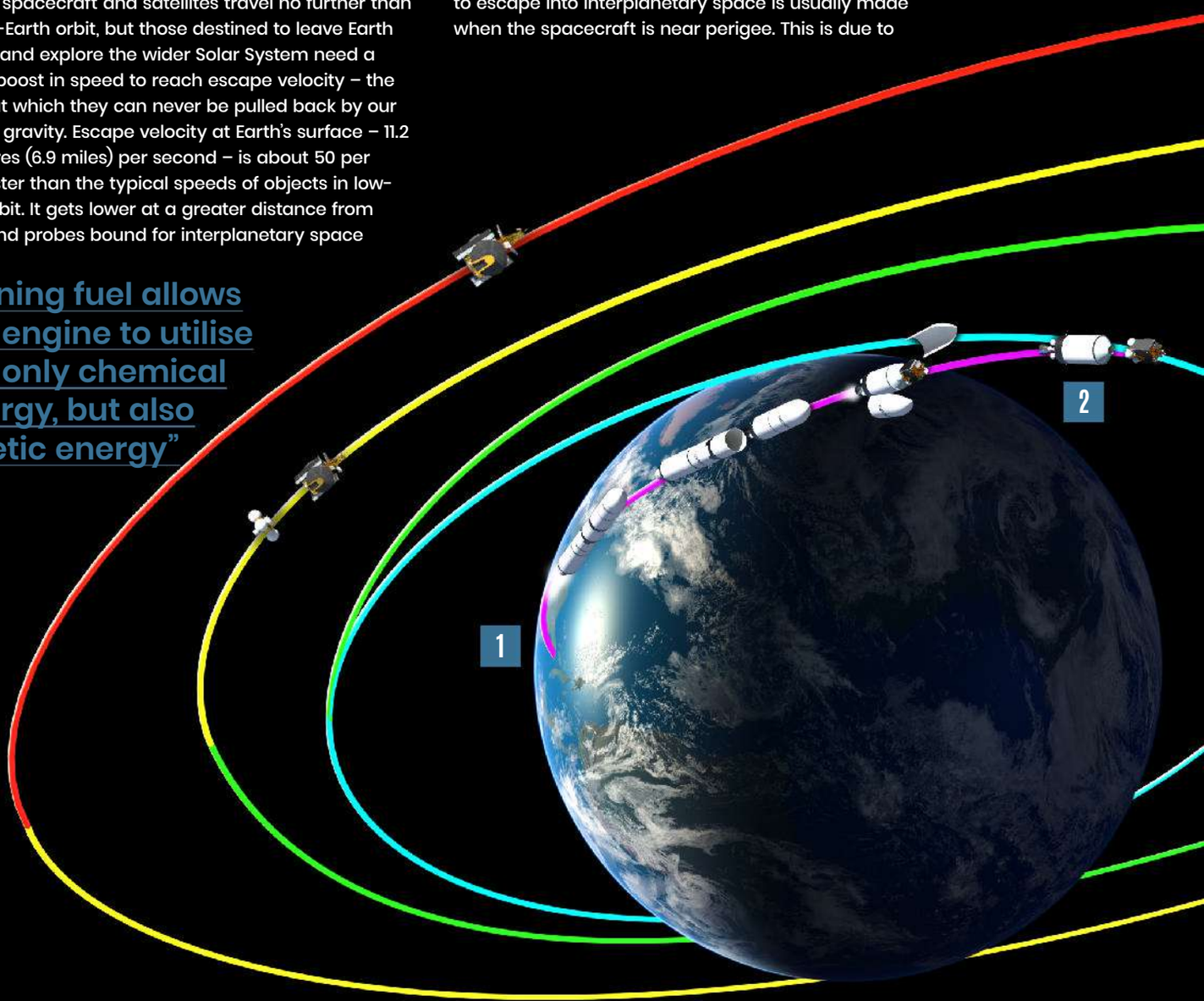
Rockets are the key to exploring our Solar System, but how do they get from orbit to deep space?

The first stage of any spaceflight involves launch from Earth's surface into a relatively low orbit around 200 kilometres (124 miles) up – above the vast majority of the atmosphere. Here gravity is almost as strong as it is on the surface, but friction from Earth's upper atmosphere is very low. If the uppermost stage of the rocket is moving fast enough, it can maintain a stable circular or elliptical trajectory where the pull of gravity and the vehicle's natural tendency to fly off in a straight line cancel each other out.

Many spacecraft and satellites travel no further than this low-Earth orbit, but those destined to leave Earth entirely and explore the wider Solar System need a further boost in speed to reach escape velocity – the speed at which they can never be pulled back by our planet's gravity. Escape velocity at Earth's surface – 11.2 kilometres (6.9 miles) per second – is about 50 per cent faster than the typical speeds of objects in low-Earth orbit. It gets lower at a greater distance from Earth, and probes bound for interplanetary space are often first injected into elongated or elliptical orbits by a carefully timed burst of thrust from an upper-stage rocket, which may remain attached to the spacecraft for the rest of its interplanetary flight. In such an orbit, the spacecrafts' distance from Earth can range from hundreds to thousands of kilometres, and its velocity will also vary, reaching a maximum when the spacecraft is closest to Earth – a point called perigee – and slowing down further out.

Surprisingly, however, the critical rocket burn used to escape into interplanetary space is usually made when the spacecraft is near perigee. This is due to

"Burning fuel allows the engine to utilise not only chemical energy, but also kinetic energy"



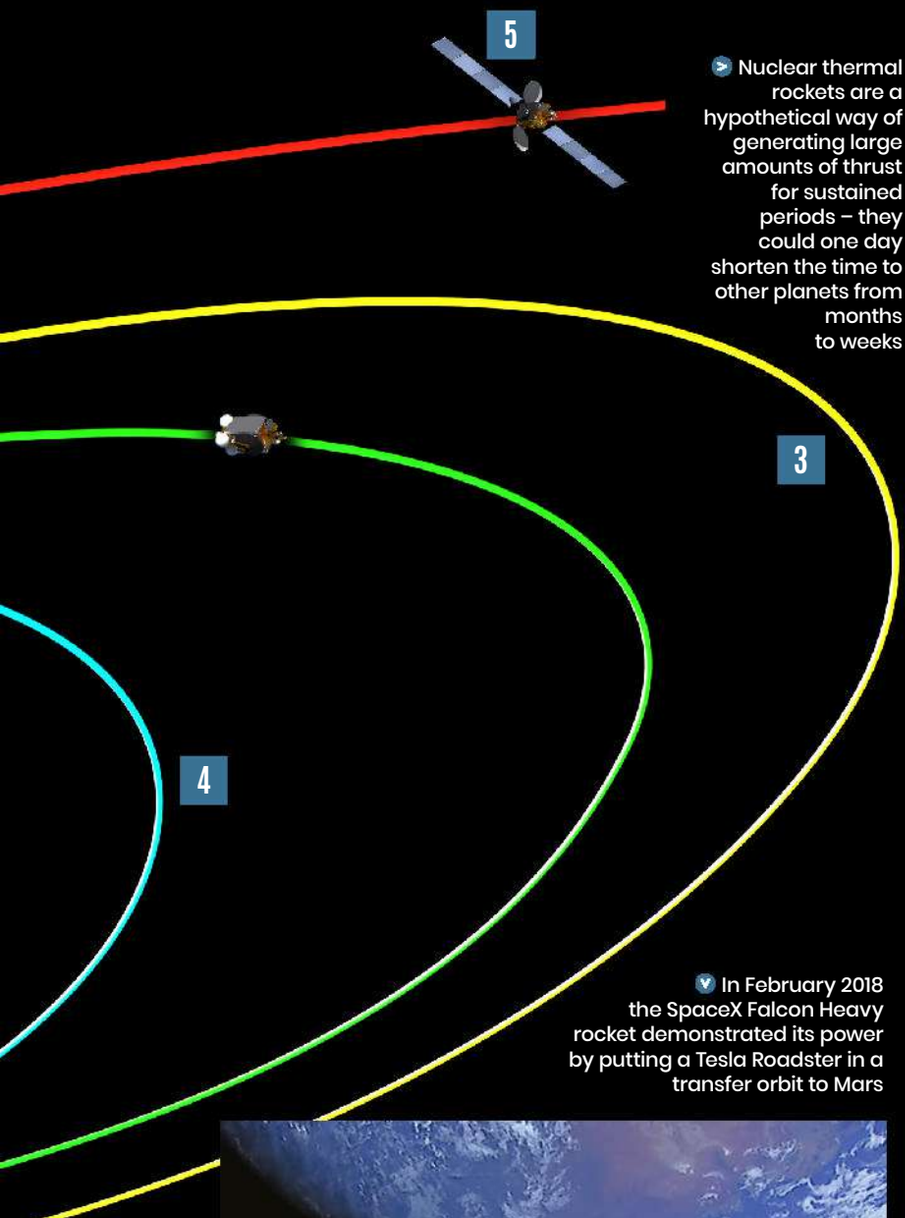
1 Low-Earth orbit
Directly after launch, a space probe usually enters a roughly circular low-Earth orbit a couple of hundred kilometres above Earth.

2 Ellipse around the Earth
One or more precisely timed rocket burns nudge the spacecraft onto a more elliptical trajectory that varies in distance from Earth.

3 Picking up speed
In an elliptical transfer orbit the probe moves more slowly at greater distance from Earth and much more quickly around its closest approach.

4 Close burn
The Oberth effect allows a spacecraft's rockets to deliver more thrust for a set amount of fuel when it's already moving at high speed and close to Earth.

5 Hohmann transfer orbit
A final burn allows the probe to break free from Earth on a trajectory that looks spiral from our point of view, but is actually a segment of an elliptical orbit around the Sun.



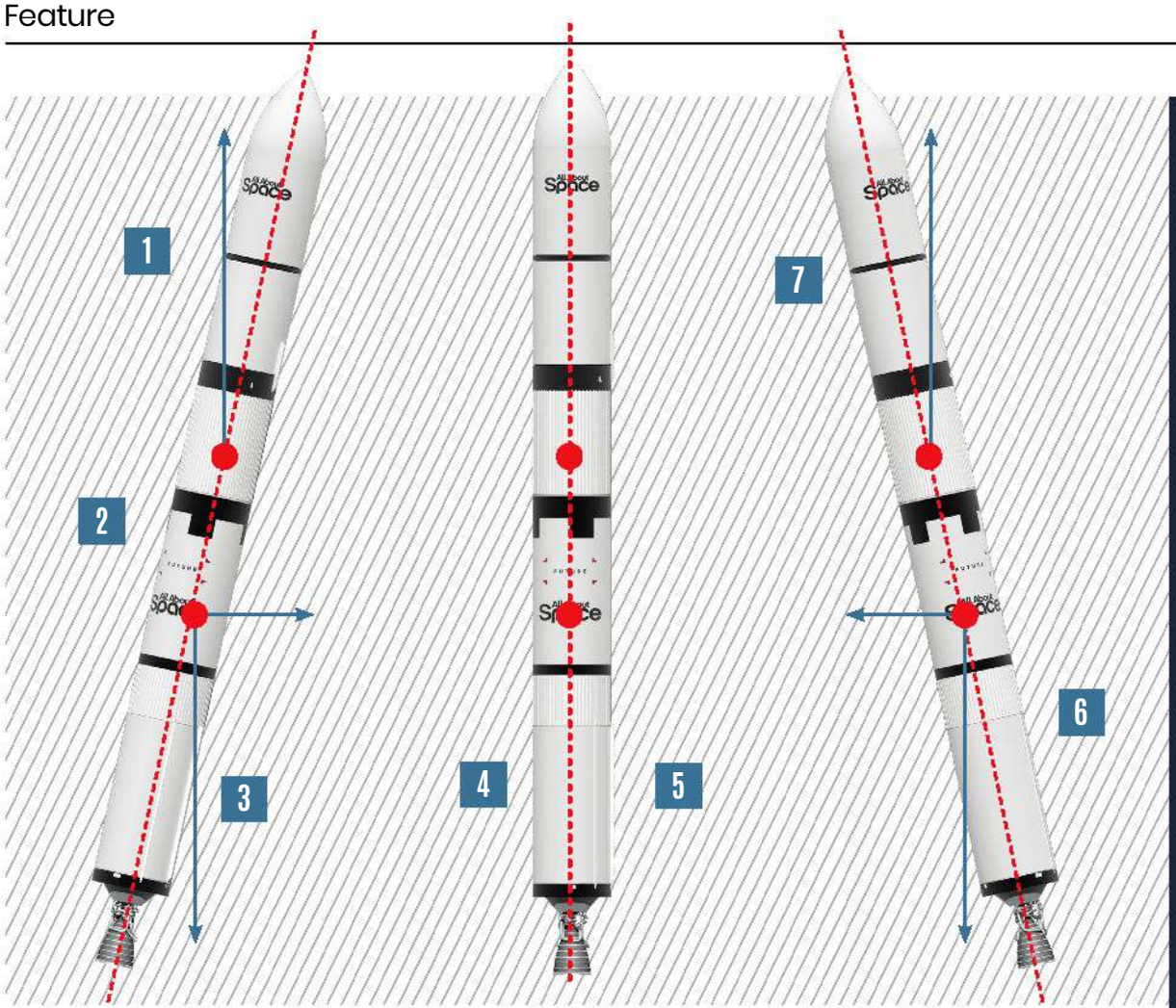
Nuclear thermal rockets are a hypothetical way of generating large amounts of thrust for sustained periods – they could one day shorten the time to other planets from months to weeks

the so-called 'Oberth effect', an unexpected property of rocket equations that means a rocket is more efficient when it's moving at higher velocity. One way to understand this is that burning a spacecraft's fuel allows the engine to utilise not only its chemical energy, but also its kinetic energy, which is greater at higher speeds. On balance, the additional rocket thrust needed to reach escape velocity from a low altitude at higher speed is less than that needed to escape from a high altitude when moving at a lower speed.

Spaceflight engineers and mission planners often refer to the 'Delta-v' required to accomplish a specific flight manoeuvre, such as a change in orbit. Strictly speaking, the term 'Delta-v' means change in velocity, but engineers use it specifically as a measure of the amount of 'impulse', or thrust force over time, needed to accomplish a manoeuvre. Broadly speaking, missions are planned around a 'Delta-v budget' – how much thrust they can generate for how long using the spacecraft's onboard fuel supplies.

Sending a spacecraft from one planet to another with minimum Delta-v requirements involves injecting it into an elliptical orbit around the Sun, called a Hohmann transfer orbit. The spacecraft travels along a segment of the elliptical path that resembles a spiral track between the orbits of the two planets, and requires no further thrust along its journey. On arrival at its target object it may use gravity alone to enter its final orbit, or it may require a burst of rocket thrust in the opposite direction – usually accomplished by simply turning the spacecraft around in space and firing the motor – before it can achieve a stable orbit.

In February 2018 the SpaceX Falcon Heavy rocket demonstrated its power by putting a Tesla Roadster in a transfer orbit to Mars



TAKING FLIGHT

Rockets must delicately balance and control powerful forces in order to make it through Earth's atmosphere and into space

A rocket generates thrust using a controlled explosion as fuel and oxidant undergo a violent chemical reaction. Expanding gases from the explosion are pushed out of the back of the rocket through a nozzle – a specially shaped exhaust that channels the hot, high-pressure gas created by combustion into a stream that escapes from the back of the nozzle at hypersonic speeds, more than five times the speed of sound.

Isaac Newton's third law of motion states that every action has an equal and opposite reaction, so the 'action' force that drives the exhaust out of the rocket nozzle must be balanced by an equal and opposite force pushing the rocket forwards. Specifically, this force acts on the upper wall of the 'combustion chamber', but since the rocket motor is integral to each rocket stage, we can think of it acting on the rocket as a whole.

Although the forces acting in both directions are equal, their visible effects are different because of another of Newton's laws, which explains how objects with greater mass need more force to accelerate them by a given amount. So while the 'action' force rapidly accelerates a small mass of exhaust gas to hypersonic speeds each second, the equal 'reaction' force produces a far smaller acceleration in the opposite direction on the far greater mass of the rocket.

As the rocket gains speed, keeping the direction of motion closely aligned with the direction of thrust is critical – gradual adjustments are needed to steer the rocket towards an orbital trajectory, but a severe misalignment can send the rocket whirling out of control. Most rockets, including the Falcon and Titan series and the Saturn V Moon rocket, steer using 'gimballed' engines, mounted so that the entire rocket motor can pivot and vary the direction of its thrust from moment to moment. Other steering options include using external vanes to deflect the exhaust gases as they escape the rocket engine – most effective with solid-fuelled rockets that lack a complex motor – and auxiliary engines, small 'thruster' rockets mounted on the sides of the rocket stage.

1 Vertical ascent
Forces act all along the central axis, with the rocket's gravity and any drag due to air resistance pulling it downwards, and thrust pushing it upwards.

2 Restoring force
If the centre of pressure is below the centre of gravity, the torque force will tend to twist the rocket back to a stable path.

3 Fins or gimbals
Today most rockets use gimballed motors to adjust their direction instead of fins.

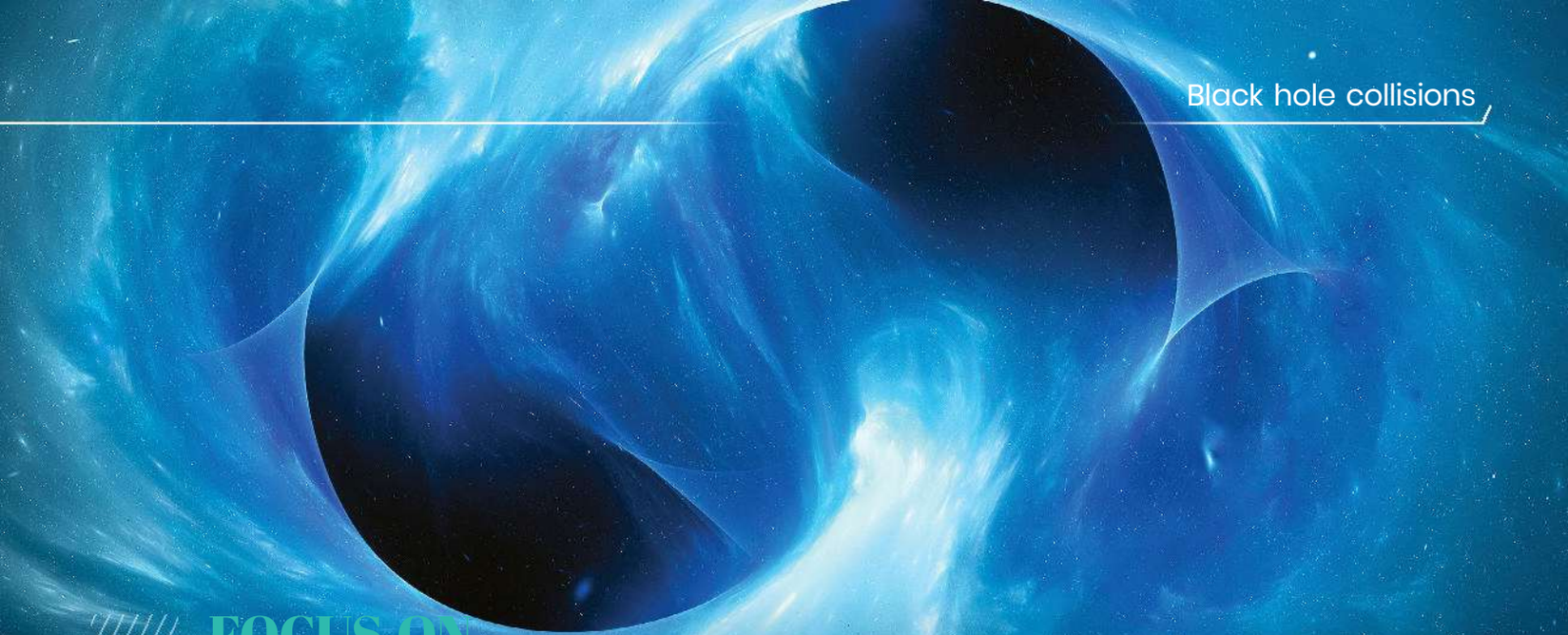
4 Twisting forces
When the rocket's thrust isn't aligned to its motion, lift and drag combine to produce a force called torque.

5 Centre of gravity
The centre of gravity is the exact mid-point in distribution of mass. This changes during the flight.

6 Centre of pressure
The centre of pressure is the point where the aerodynamic forces of drag and lift act.

7 Off-axis flight
Fins help keep the rocket stable, but they and the rocket's body both generate lift, a force that pushes the rocket to one side.

© NASA; SpaceX; Adrian Mann



FOCUS ON

BLACK HOLES SPOTTED ON A COLLISION COURSE

NASA's Chandra X-ray Observatory has seen the first evidence of black holes in dwarf galaxies about to impact

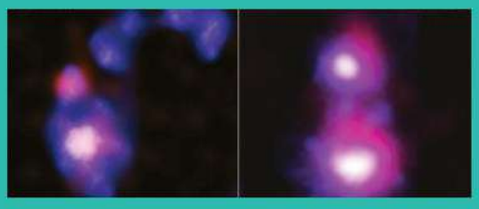
Reported by Robert Lea

Astronomers have spotted not one but two dwarf galaxy black hole duos on separate collision courses, the first observational evidence of such a cosmic clash. Just as the black holes are heading for a collision and merger that will leave a more massive black hole behind, the dwarf galaxies they sit in will also merge and form a larger galaxy. The findings could have important implications for our understanding of how these cosmic titans and the galaxies they inhabit grew in the early universe. Scientists examined the colliding black hole pairings using NASA's Chandra X-ray Observatory and found that as the dwarf galaxies are racing towards each other, they are pulling in gas that is 'feeding' their inhabitant black holes, causing them to grow even before the merger.

Dwarf galaxies are small galaxies that contain stellar mass equivalent to no more than around 3 billion times that of the Sun. By comparison, the entire Milky Way is believed to contain a stellar mass around 60 billion times that of our star. Scientists think that in the first hundreds of millions of years after the Big Bang, the early universe was replete with these dwarf galaxies, most of which merged to form larger galaxies like ours.

These early galaxies have thus far been impossible to observe due to the fact they are extremely faint and are located at great distances away. Astronomers have, however, seen closer dwarf galaxies in the process of merging, but there has been no sign of black holes in those galaxies until now. "Astronomers have found many examples of black holes on collision courses in large galaxies that are relatively close by," Marko Micic, a researcher at the University of Alabama at Tuscaloosa and a member of the study team, said. "But searches for them in dwarf galaxies are much more challenging, and until now had failed."

To overcome the challenge of spotting black holes in merging dwarf galaxies, the team conducted a systematic survey of deep Chandra X-ray observations and compared them with optical and infrared data. Because the material around the black holes is heated to millions of degrees, it produces large amounts of high-energy light in the form of X-rays, which Chandra is adept at spotting. Hunting for pairs of bright X-ray sources in colliding dwarf galaxies, the researchers spotted two examples. The closest pair of colliding dwarf galaxy black holes, dubbed Mirabilis, is located 760 million light years from Earth in the galactic cluster Abell 133. These dwarf galaxies appear to be in the later stages of merging, with the tidal effects of the collision causing the formation of a long tail of material. The more distant merger is located around 3.2 billion light years away in the galactic cluster Abell 1758S and is in an earlier stage of collision.



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INSTANT EXPERT

WHICH PLANETS HAVE RINGS?

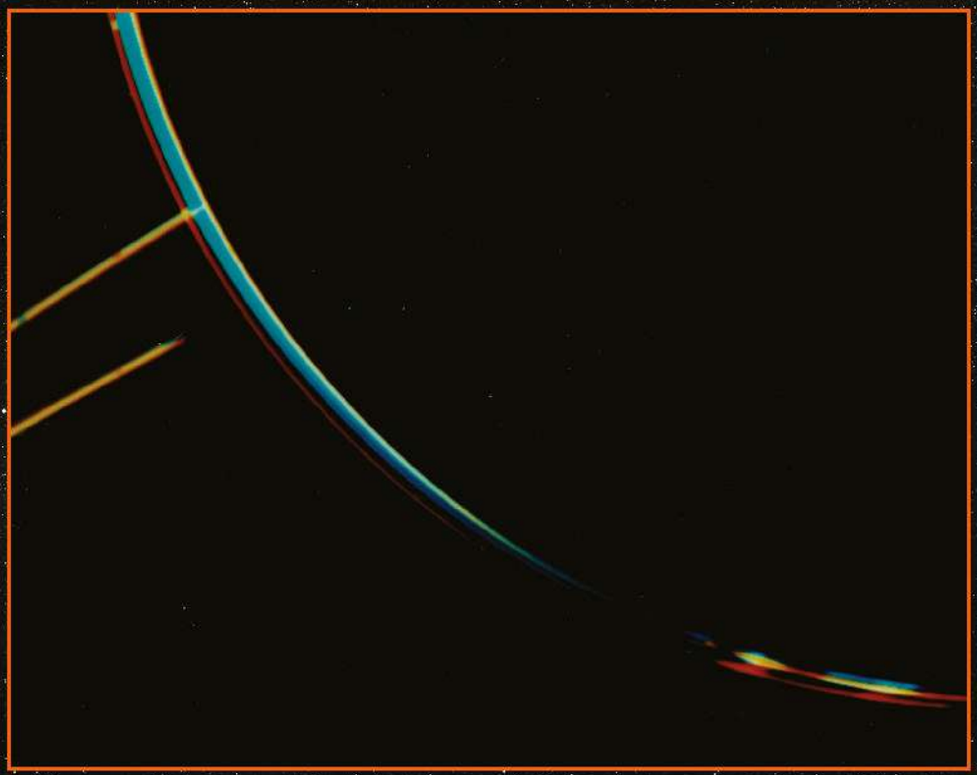
Saturn is famously encircled by a bright and complex ring system, but it's not alone in possessing one

Saturn's rings have become a graphic shorthand for planets, with logos to bed covers to stickers all featuring ringed planets. But Saturn is not alone in possessing a planetary ring system, with four planets and two dwarf planets in the Solar System alone also boasting rings. Planetary rings are made up of lumps of dust and ice orbiting their parent body, like billions of tiny moons. It's theorised that they're made of debris left behind from the formation of the planet, from the collision and destruction of moons or from a moon that got too close to the planet and was pulled apart by tidal forces.

Saturn's rings are the most famous in the Solar System and were a source of great puzzlement when Galileo Galilei first trained a telescope on the planet in 1610 – at first he thought Saturn was a triple planet. It wasn't until 1655 that Christiaan Huygens realised that what he was seeing was in fact a disc. The rings consist of seven major divisions, generally of the same thickness but of greatly varying density. Saturn's many moons also affect the rings, with Prometheus' gravity shepherding the edge of one into a sharp boundary and Enceladus adding ice crystals to the E ring.

Despite being closer to us, Jupiter's ring system was only discovered when Voyager 1 flew past the gas giant in 1979. It has four sections believed to be made up of dust, but it's very diffuse compared to Saturn's ring system. Next up is Uranus, whose rings are much more distinct than Jupiter's, yet they were also only discovered in the 1970s due to the planet's great distance from Earth. Uranus famously rotates on its side, so its rings appear to be north-south as they orbit around the tilted equator. Neptune also has a ring system, which is largely made up of dust rather than ice. The density of Neptune's ring system approaches that of Saturn's thinner rings, but the rings remain faint and dark due to organic material within them.

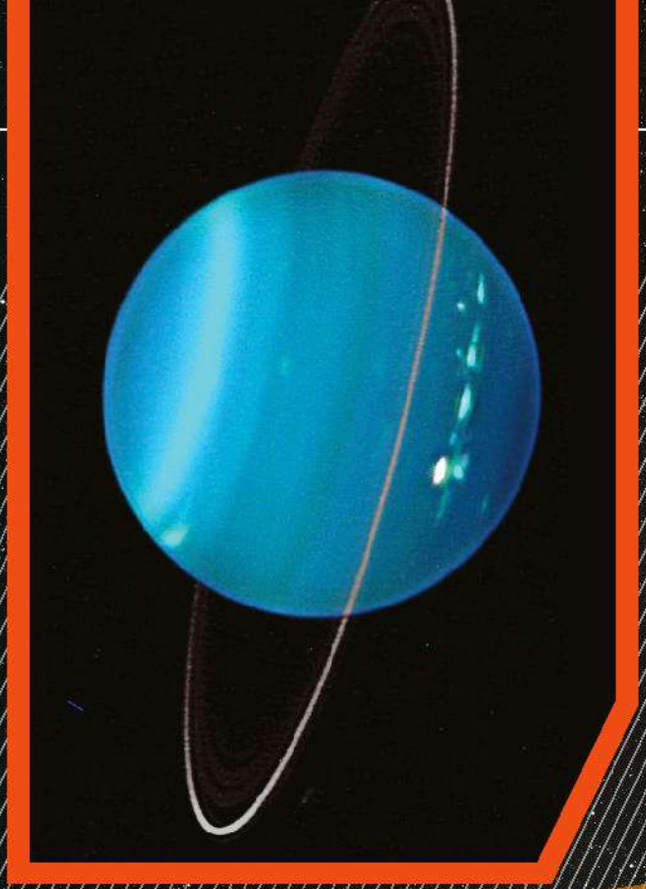
In 2013, dips in brightness of stars observed around the dwarf planet Chariklo, orbiting between Saturn and Uranus, led to the conclusion that it has a ring system. Chiron, another dwarf planet in the same region, is also thought to have rings. Both Chiron and Chariklo are centaurs, small icy bodies crossing the orbits of giant planets. It's thought that their rings may have formed from surface material that was pulled by tidal forces when they got too close to these giant planets.



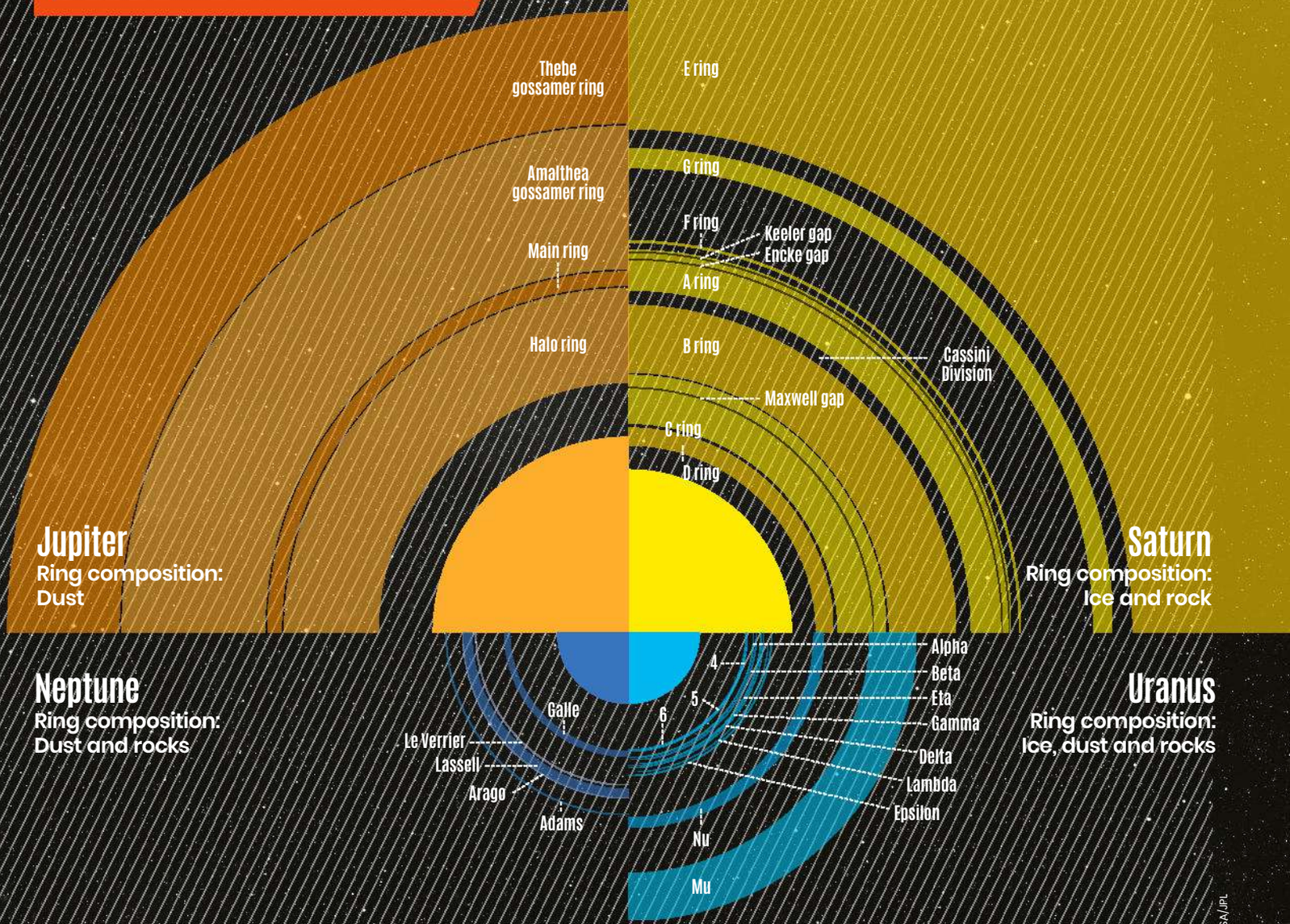
Jupiter's faint ring system is shown in this colour composite as two light-orange lines. It was taken in Jupiter's shadow through orange and violet filters

An infrared composite of Uranus' rings taken with the Keck telescope

BIO
ROBIN HAGUE
Robin is a science writer, focusing on space and physics. He is the current head of launch at Skyrora, coordinating launch opportunities for Skyrora's vehicles and liaising with UK launch regulators.



"Four planets and two dwarf planets in the Solar System alone also boast rings"



Jupiter
Ring composition: Dust

Saturn
Ring composition: Ice and rock

Neptune
Ring composition: Dust and rocks

Uranus
Ring composition: Ice, dust and rocks

© NASA/JPL

25 GREAT SPACE DAYS OUT

From fascinating hardware and rocket launches to planetariums and observatories, Earth is full of out-of-this-world attractions

Written by Stuart Atkinson

One day there will be museums on the Moon and Mars, where visitors will be able to see the probes, landers and rovers that explored them back in the 20th century. But today our own planet has many out-of-this-world attractions. Just like the universe itself, the world is full of hidden astronomical wonders that deserve exploration. Catching some Sun on a beach is fine, and so is a shopping trip or visit to the theatre during a city break, but for a change, how about a day out where you can learn more about space, space exploration and astronomy?

For anyone wanting to know more about the night sky, there are some wonderful planetariums. Most hold seasonal shows with special themes, and now their projection systems are so technologically advanced that you can enjoy full-dome 3D films as you lay back in your seat. There are many educational space centres that double as observatories in the evening, offering fascinating exhibitions by day and real-life expert-led stargazing by night – and perhaps even the chance to peer through a big telescope.

Elsewhere there are fabulous museums stuffed with natural space-related wonders such as Moon rocks and meteorites from other planets. Many are also home to landmark space artefacts and hardware with incredible stories to tell. A Saturn V rocket, the Apollo 11 capsule and even Neil Armstrong's spacesuit can all be viewed if you know where to look. More modern spaceships are also on display – the Space Shuttle Atlantis can now be visited in Florida, and if you visit London's Science Museum you'll be able to see Tim Peake's charred Soyuz re-entry capsule on show. Most of the venues on our list also have gift shops, so if you want a souvenir of your visit you'll be able to buy everything from pens and books to telescopes and a portable planetarium of your very own.

1 JODRELL BANK DISCOVERY CENTRE

Marvel at the size of the iconic Lovell Telescope at the UK's centre of radio astronomy

Where: Macclesfield, Cheshire
Website: jodrellbank.net

Home to the world-famous Lovell Telescope, a visit to Jodrell Bank makes for an exhilarating day out. Seeing the near 90-metre (295-foot) high radio telescope dish up close is an incredible experience, and you might even see it moving on its rails as it's aimed at a distant star or galaxy. The Discovery Centre's modern exhibitions, interactive displays and galleries will help you understand how the telescope works and what it's looking for.

You'll also find 35 acres of gardens and arboretum complete with picnic areas, a playground, galaxy garden and the pop-up Potting Shed Café. There's plenty of extra activity throughout the year too, including the ever-popular family science shows, an evening lecture series and, of course, the hugely popular annual science and music festival, Bluedot.

The Milky Way from Kielder Observatory

3 KIELDER OBSERVATORY

A stargazer's paradise near the Scottish border

Where: Northumberland
Website: kielderobservatory.org

Though you can roam about outside around the observatory grounds during the day, this observatory – its location near the Scottish border chosen because of a lack of light pollution – is only open for specific events. Tickets have to be booked in advance and go very quickly. The most popular is February's Aurora Nights, though Night Sky Safaris and astrophotography sessions are also staged. Check the website for dates.

2 ROYAL OBSERVATORY EDINBURGH

Scottish astronomy in a Victorian telescope dome

Where: Edinburgh, Scotland
Website: roe.ac.uk

High on a hill above Scotland's capital, this is the place to go if you want to hold a meteorite, explore the observatory's historic dome and look at planets and the Moon through telescopes – clear skies allowing – at the centre of astronomy in Scotland.

4 TECHNIQUEST

Hands-on science exhibits and a full-dome planetarium

Where: Cardiff, Wales
Website: techniquest.org

This modern and innovative science and technology discovery centre in the Welsh capital's buzzing Cardiff Bay has over 160 hands-on interactive exhibits. It also boasts a planetarium which uses a full-dome projector to explore the night sky during shows aimed at audiences of all ages.

5 THE MILLS OBSERVATORY

Britain's first purpose-built public observatory

Where: Dundee, Scotland
Website: leisureandculturedundee.com/welcome-mills-observatory-0

This imposing observatory enjoys a magnificent woodland setting on the summit of Balgay Hill. Inside you'll find fascinating space exploration and astronomical displays, a planetarium and a fully computerised telescope that's used for public viewing events – weather permitting.

© Getty / Royal Observatory Edinburgh / Kielder Observatory

The National Space Centre includes a 360-degree full-dome cinema

6 ROYAL OBSERVATORY GREENWICH

East meets west at the home of GMT and UTC

Where: Greenwich, London
Website: rmg.co.uk/royal-observatory

Visitors and TV crews alike flock in their thousands to stand on the Prime Meridian here, where east meets west at longitude zero degrees. It might be an imaginary line – marked with copper on the ground – but importantly for astronomers, it's where Coordinated Universal Time (UTC) is measured from. The observatory overlooks the River Thames and features an impressive 18-tonne Victorian telescope and London's only planetarium.

7 THE NATIONAL SPACE CENTRE

Visit the UK's largest attraction dedicated to space exploration

Where: Leicester, UK
Website: spacecentre.co.uk

The National Space Centre boasts six interactive galleries, the UK's largest planetarium, a unique 3D simulator experience and the opportunity to see a piece of Moon rock collected by the crew of Apollo 17. Pride of place belongs to the iconic 42-metre (138-foot) Rocket Tower, which houses not just one but two real rockets – a Blue Streak and a Thor Able. The ticket also includes entry to the on-site Sir Patrick Moore Planetarium.

Royal Observatory Greenwich contains London's only planetarium

Tim Peake's Soyuz spacecraft at the Science Museum

8 SCIENCE MUSEUM

See Tim Peake's Soyuz spacecraft and Apollo 10's Command Module

Where: London
Website: sciencemuseum.org.uk

An absolute must-visit for anyone interested in space exploration, London's Science Museum has seven floors of exhibits, including a recreation of the Eagle Lunar Module on the Moon, the actual Apollo 10 Command Module and the Soyuz TMA-19M spacecraft which carried Tim Peake to the International Space Station and back in 2016. Its theatre also shows *Legend of Apollo*, a 3D computer animation based on the Apollo lunar landings.

9 THE OBSERVATORY SCIENCE CENTRE AT HERSTMONCEUX

Six green domes of historic telescopes are the centrepiece of this hands-on experience

Where: Hailsham, East Sussex
Website: the-observatory.org

Home to the giant 2.4-metre (8.1-foot) Isaac Newton Telescope since 1967, this science centre offers daily telescope tours, interactive hands-on exhibits and spectacular science shows. The centre stages an annual astronomy festival in September and hosts courses such as Introduction to Astroimaging and a 12-week Astronomy and Space for Beginners course.

10 SOUTH DOWNS PLANETARIUM AND SCIENCE CENTRE

See a show dedicated to local hero Tim Peake

Where: Chichester, West Sussex
Website: southdowns.org.uk

The UK's biggest planetarium can be found on the grounds of Chichester High School's campus. It runs excellent stargazing shows such as Summertime Stars, Moon and Planets and Summer Nights, Shooting Stars, as well as one show dedicated to UK astronaut Tim Peake, who is from the Chichester area. Nearby at the Novium, you can see the Tim Peake: An Extraordinary Journey exhibition.

11 NATURAL HISTORY MUSEUM

See Moon rock and meteorites at this world-class museum

Where: London
Website: nhm.ac.uk

Although it's the Science Museum just around the corner that has the most space artefacts, this great museum holds the only piece of Apollo Moon rock owned by the UK – though the National Museum of Wales in Cardiff has Moon rock on loan. It also has over 2,000 individual meteorites in its collection, gathered from locations all over the world.

12 CHARLEVILLE COSMOS CENTRE

There's no better place for stargazing than the Outback

Where: Charleville, Australia
Website: cosmoscentre.com

Deep in the Australian outback, it's a short flight from Brisbane. Visit during the daytime and you can handle meteorites. After dark the roof slides off a nearby observatory for spectacular views of the southern sky and guided stargazing using a fleet of huge Meade telescopes.

13 ROQUE DE LOS MUCHACHOS OBSERVATORY

This mountaintop houses Europe's best telescopes

Where: La Palma, Canary Islands
Website: N/A

The air may be thin up on this volcano, but it's thick with Europe's best telescopes. Book ahead and you can visit one on a 90-minute tour, usually the William Herschel Telescope, a 4.2-metre (13.7-foot) reflector. La Palma is where Europe's biggest telescopes live.

14 PIC DU MIDI OBSERVATORY

Stargaze from a telescope-studded mountaintop

Where: Pyrenees, France
Website: picdumidi.com

This observatory, positioned on a high ridge in the Pyrenees, can be visited by day via cable car from La Mongie ski resort. Its Night at the Summit package includes the cable car, meals, an astronomy talk and an overnight stay, during which you can see a telescope NASA used to map the Moon.

© Getty / The National Space Centre / Trustees of the NHM, London

15 THE PLACE CAPTAIN KIRK WAS BORN

Visit the future birthplace of a science-fiction legend

Where: Riverside, Iowa
Website: N/A

According to *Star Trek* lore, Captain James Tiberius Kirk, the most famous captain of the federation starship USS Enterprise, was – or will be – born in the town of Riverside, Iowa, on 22 March 2233, where he was raised by his parents George and Winona Kirk. Every year, tens of thousands of fans of the sci-fi franchise visit the town to see and pose beside a plaque dedicated to Captain Kirk.

Johnson Space Center's Mission Control

16 USS HORNET SEA, AIR AND SPACE MUSEUM

See the splashdown recovery ship for Apollo 11 and Apollo 12, and plenty of other memorabilia

Where: San Francisco, California
Website: uss-hornet.org

The huge and impressive aircraft carrier that retrieved the crews of both Apollo 11 and 12 after splashdown has fascinating displays of memorabilia, including photos and an Apollo Command Module used in testing by NASA astronauts.

17 ARMSTRONG AIR AND SPACE MUSEUM

The hometown of Neil Armstrong has artefacts from some of his greatest achievements

Where: Wapakoneta, Ohio
Website: armstrongmuseum.org

This museum is designed to look like a Moon base, and it's convincing on the inside too. Here you'll find Neil Armstrong's Gemini 8 and most of his Apollo 11 spacesuit – his gloves and helmet are on display at the Smithsonian National Air and Space Museum. You can also see a piece of Moon rock and the historic Gemini 8 spacecraft

19 NASA MISSION CONTROL AT JOHNSON SPACE CENTER

Drop in on the International Space Station's Mission Control

Where: Houston, Texas
Website: spacecenter.org

Second only to witnessing a rocket launch must be taking the hallowed Level 9 Tour at the Johnson Space Center, which lets you see the International Space Station (ISS) Mission Control room. The tram tour also includes historic Mission Operations Control Room 2, used in the Apollo era, a Saturn V rocket designed for the cancelled Apollo 19

Mobile Quarantine Facility onboard the USS Hornet

18 GRIFFITH OBSERVATORY

Peer through the world's most popular telescope

Where: Los Angeles, California
Website: griffithobservatory.org

Over 7 million people have looked through the 12-inch Zeiss refracting telescope on the roof of the Griffith Observatory, which has featured in countless films and TV series. You can queue up to take a look yourself, then gaze out across LA as the lights come on before descending to the front lawn to look through a bevy of large telescopes set up by volunteers each evening.

20 LOWELL OBSERVATORY

See where Pluto was discovered on Mars Hill in 1930

Where: Flagstaff, Arizona
Website: lowell.edu

During the day tour you can see the historic Pluto Discovery Telescope and the Clark Telescope, then walk the fabulous scale models of the Solar System and the universe in the surrounding ponderosa pine forest on Mars Hill. At dusk, staff set up huge telescopes on the lawn. Below the observatory is the historic town of Flagstaff, now a dark-sky community, with the famous Route 66 running through it.

The Apollo Lunar Module in the Boeing Milestones of Flight Hall

24 SMITHSONIAN NATIONAL AIR AND SPACE MUSEUM

See the only hardware that returned from the first Moon landing

Where: Washington, DC
Website: airandspace.si.edu

Many think that the Smithsonian is the finest space museum in the world, but it certainly houses the most precious space artefact in the world. Housed in the Boeing Milestones of Flight Hall is the Apollo 11 Columbia Command Module that carried Armstrong, Aldrin and Collins to the Moon's orbit and back. The fantastic museum also features an artefact-packed Apollo to the Moon exhibition, but its star attraction is the Space Shuttle orbiter Discovery, which flew into space 39 times before being retired in 2011.

21 METEOR CRATER

A Moon-like hole in the ground where Apollo astronauts trained

Where: Winslow, Arizona
Website: meteorcrater.com

This hole, left by a small asteroid slamming into the planet 50,000 years ago, is the best preserved impact crater you can see in the world, and it's a stunning sight. After walking along the viewing platform that runs around the rim of the crater, you can visit the museum and see a piece of the asteroid that blasted out the hole. Complete with telescopes, there's a new museum and walking trails. The crater can be found on the way to the Grand Canyon via Flagstaff.

22 HAYDEN PLANETARIUM

See Neil deGrasse Tyson's planetarium at the American Museum of Natural History

Where: New York
Website: amnh.org

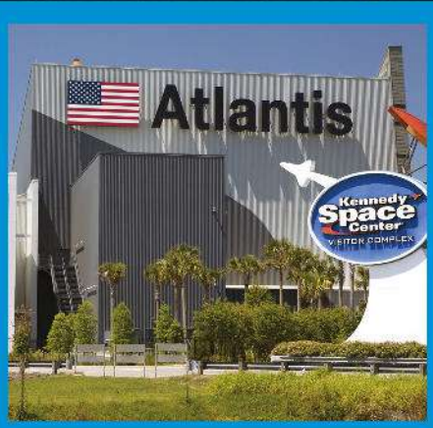
The 'world's largest cosmic atlas' is the claim of the Hayden Planetarium, a cutting-edge installation at the American Museum of Natural History near Central Park in Manhattan. Directed by Neil deGrasse Tyson, the planetarium uses a Zeiss Mark IX star projector to produce film-like shows with awesome production values.

23 KENNEDY SPACE CENTER VISITOR COMPLEX

See a Saturn V rocket while you're in Florida

Where: Florida
Website: kennedyspacecenter.com

Space Shuttle Atlantis is now the primary reason for many to visit Florida's Kennedy Space Center, but the sight of a mighty Saturn V rocket – one of the largest ever built and exactly the same as the one that took Apollo 11 to the Moon – lying on its side is absolutely stunning. Apollo 14's Command Module is also on display here.



25 CERRO PARANAL

See the planet's best telescope at the 'astronomy capital of the world'

Where: Atacama Desert, Chile
Website: www.eso.org/public/about-eso/visitors

The highest, driest place in the world is where you can see the planet's most advanced ground-based optical instrument, the European Southern Observatory's Very Large Telescope (VLT) array. Visitors are welcome to join a guided tour on Saturdays, which includes a close-up of the four telescopes.

© Getty / USS Hornet Sea, Air & Space Museum / NASA / Mark Avino/Smithsonian's National Air and Space Museum

FOCUS ON

HUBBLE IMAGES AFFECTED BY STARLINK STREAKS

Over five per cent of recent shots contained satellite trails

Reported by Robert Lea

The effects of satellites on our view of the universe is getting worse. The findings may confirm the fears of astronomers who argue that satellite constellations such as SpaceX's fleet of over 4,000 Starlink spacecraft stand to severely impact astronomy. These fears were initially confined to astronomers working with ground-based observatories, but as humanity's exploitation of the space around our planet has burgeoned and plans for so-called 'megaconstellations' of satellites have progressed, those concerns have spread to colleagues working with space-based instruments.

A team of researchers, including over 11,000 citizen scientists from the Hubble Asteroid Hunter project, scoured through images produced by the Hubble Space Telescope between 2002 and 2021. The team found that 2.7 per cent of Hubble's images, with a typical exposure time of 11 minutes, were crossed by satellites. Additionally, the probability of finding satellite trails in Hubble images has increased with time from 3.7 per cent in 2002 to 5.9 per cent in 2021.

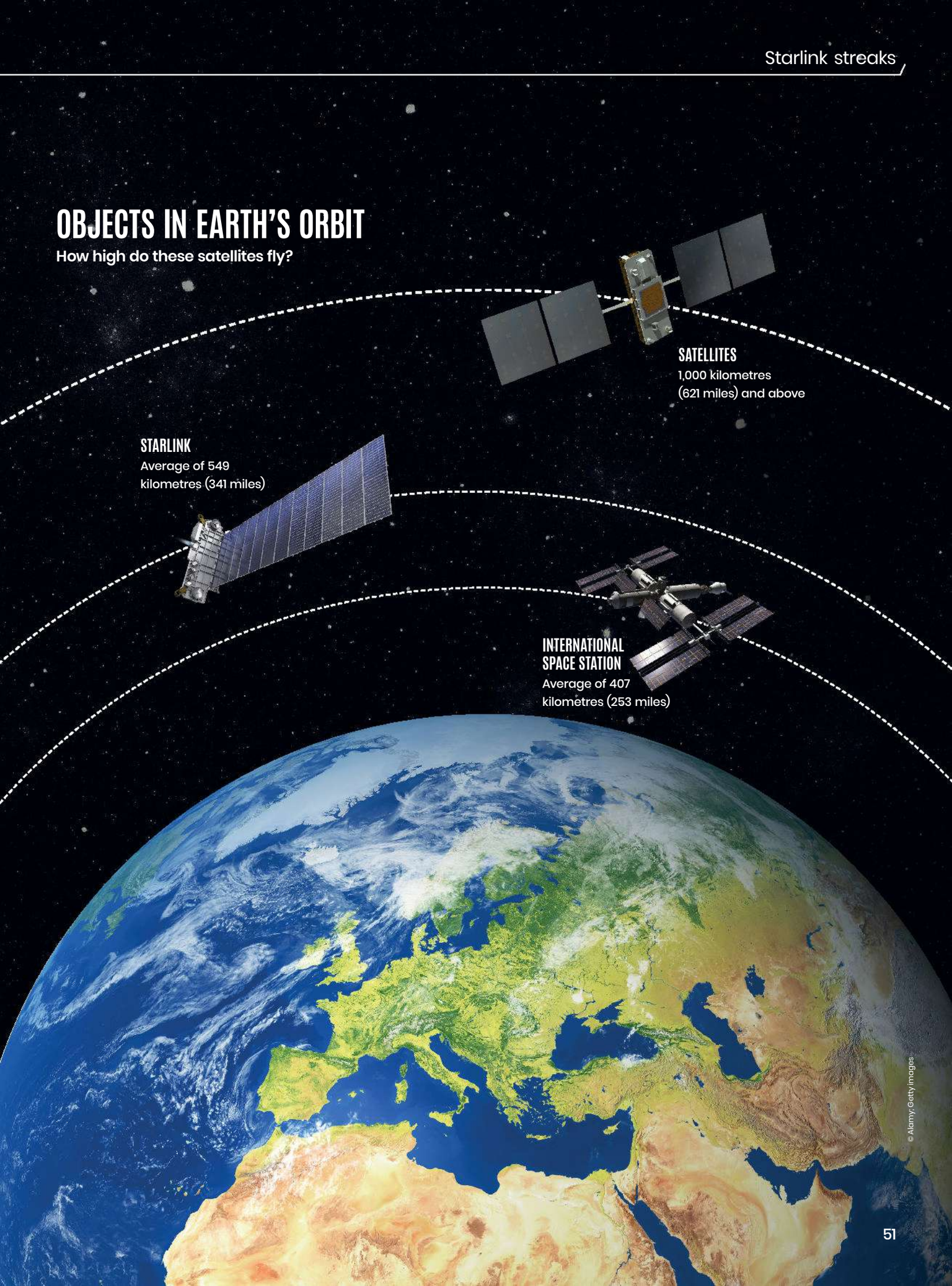
Hubble's orbit has decayed since its launch in 1990. In this lower orbit, the telescope has become increasingly sensitive to satellites in higher orbits. These spacecraft affect the images produced by Hubble by appearing as bright steaks as they race past the space telescope during the period its lens is open to collect light from the universe. "With the growing number of artificial satellites currently planned, the fraction of Hubble Space Telescope images crossed by satellites will increase in the next decade and will need further close study and monitoring," the study authors wrote.

Volunteer citizen scientists looked at Hubble images and highlighted those marred by satellite streaks. Two algorithms were then used to examine the volunteer classifications – one for exposures of 11 minutes, and the other for exposures of 35 minutes. The examination revealed trails were consistent between images taken with Hubble over the two exposure times.

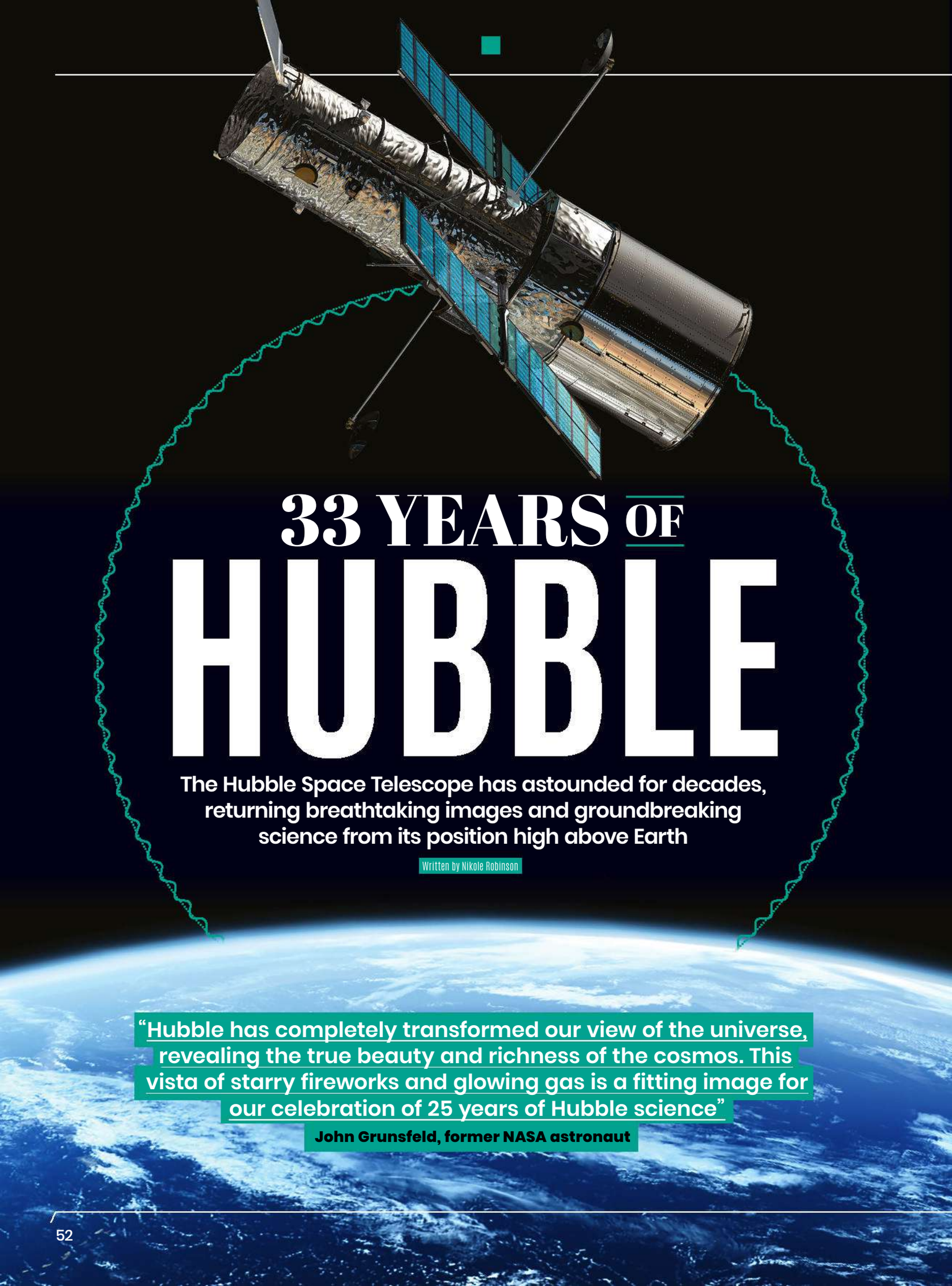
© Getty

Around 4,000 Starlink satellites have been launched so far, but more are planned

Surprisingly, streaks were found even in images taken prior to the deployment of the Starlink megaconstellation. Astronomers are concerned that the problem is only bound to get significantly worse, as only a small fraction of planned satellites is currently in orbit. Eventually, SpaceX hopes to have as many as 42,000 Starlink satellites in low-Earth orbit. British firm OneWeb has permission to launch a constellation of 648 broadband satellites and has expressed the desire to add to that up to 7,000 units with future upgraded spacecraft versions. The European Southern Observatory (ESO) predicted in 2020 that by 2030 there could be as many as 75,000 low-orbit satellites around Earth. The new findings, coming before swarms of artificial satellites reach orbit, will hopefully help establish a baseline for future studies that will assist astronomers to better assess the impact of megaconstellations on astronomy.



© Alamy; Getty Images



33 YEARS OF HUBBLE

The Hubble Space Telescope has astounded for decades, returning breathtaking images and groundbreaking science from its position high above Earth

Written by Nikole Robinson

"Hubble has completely transformed our view of the universe, revealing the true beauty and richness of the cosmos. This vista of starry fireworks and glowing gas is a fitting image for our celebration of 25 years of Hubble science"

John Grunsfeld, former NASA astronaut

No mission has ever captured the public's imagination quite like Hubble. Since its launch on 24 April 1990, the venerable space telescope has made over 1.5 million observations of planets, star clusters, nebulae and galaxies that not only look stunning, but have furthered our understanding of the universe. From its position in orbit 535 kilometres (332 miles) above our planet, Hubble is free from the atmospheric distortion that plagues ground-based observatories, giving it a clear picture. But this wasn't always the case. The first images Hubble returned were distorted; astronomers concluded that the telescope's main mirror had been sent into space flawed. Corrective optics were devised, installed by a Space Shuttle mission in 1993, and from then on its place among the stars was cemented. Even with its successor, the James Webb Space Telescope, now operational, Hubble shows no signs of slowing down.

WESTERLUND 2

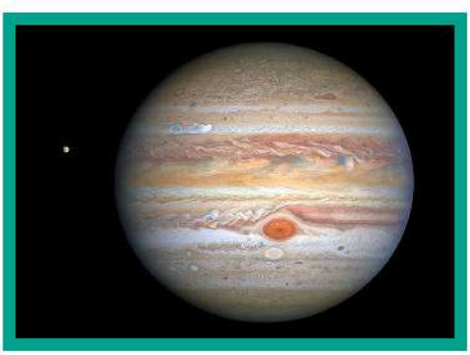
23 APRIL 2015

Stars burst to life in this mesmerising image, with topaz and amethyst-hued clouds of gas and dust lit up by the harsh radiation of the thousands of young stars speckled across the background sky. For Hubble's 25th anniversary, astronomers focused the telescope on a region known as Gum 29, 20,000 light years away in the constellation of Carina. The stellar firework just right of centre is Westerlund 2, a cluster of stars estimated to be just 2 million years old.

MESSIER 51 AND NGC 5195

25 APRIL 2005

Known as the Whirlpool Galaxy due to its glittering arms, Messier 51 is a grand-design spiral galaxy 25,000 light years away. Its sweeping swirls are where new stars are being born from dense hydrogen clouds, while its yellow centre is much older.



JUPITER AND EUROPA

25 AUGUST 2020

Snapped while Jupiter was 653 kilometres (406 miles) away, this image highlights the tumultuous bands of storms that circle the planet in opposite directions. The bright-white storm in the upper left was brewing when the image was taken, allowing scientists to see a storm in its early stages. Also on display is the smallest of the planet's Galilean moons, Europa, an icy moon suspected to have a subsurface ocean.

V838 MONOCEROTIS

3 FEBRUARY 2005

This red supergiant drew attention in 2002 when it mysteriously brightened for three months. The smoky swirls are a light echo – gas and dust reflected the light from the star's eruption, delaying it on its way to reach Hubble's instruments.

© NASA; ESA

CARINA NEBULA

24 APRIL 2007

This panoramic vista showcases 50 light years of the Carina Nebula in one majestic mosaic, moulded from 48 separate frames taken by Hubble. The billowing clouds in the region have been shaped by fierce stellar winds and radiation from massive young stars. These stellar giants grow huge and hot, but die young. Eta Carinae, a star on the left, has begun expelling material and is expected to go supernova relatively soon in astronomical terms, despite being only around 3 million years old.

"It's my favourite because of its beauty and because it contains in a single mosaic the full range of stellar lives, from their birth in dense clouds of dust and gas to the later stages where the dying stars expel matter at high velocities out into the interstellar medium"

Dr Kenneth Carpenter, Hubble operations project scientist

NGC 3603

2 OCTOBER 2007

This nebula of ionised hydrogen contains one of the most populated young star clusters in the Milky Way, showcasing stars at different stages of their lives. Within the last million years, a collapse within the cloud caused thousands of stars to spring to life, all different shapes, masses and sizes – great for researchers looking into stellar evolution. The absence of nebulosity in the central region also allows for unobstructed views of the star cluster, making it a prime target for study. This window within the clouds was carved by radiation from the hot blue stars in the middle of the cluster.

HELIX NEBULA

16 DECEMBER 2004

One of the brightest planetary nebulae looks like an eye looming in the darkness of space. These objects form when a star too small to go supernova sheds its outer layers as it runs out of fuel at the end of its life. As these gaseous layers spread out into the surrounding space, the star at the centre cools to become a white dwarf. These stellar remnants exude radiation, heating the expelled material. The Helix Nebula was the first planetary nebula observed to have cometary knots – dense filaments of gas that resemble comets with tails – dispersed within its rings of material.

SATURN SPOKES

9 FEBRUARY 2023

With Saturn's orbit of the Sun taking over 29 years, the Ringed Planet experiences seasons much slower than we do here on Earth. The northern hemisphere is currently gearing up for its autumn equinox, which will take place on 6 May 2025, taking the planet into its so-called 'spoke season'. Two dark smudges can be spotted in the B ring to the left of the planet in this recent Hubble image. As autumn approaches, these spokes will become more plentiful and pronounced. These strange radial markings can appear light or dark depending on the angle they're lit from.

HUBBLE ULTRA DEEP FIELD

21 SEPTEMBER 2006

Pointing Hubble in the direction of an 'empty' region of space, 800 exposures were collected over a period of 114 days to obtain this astonishingly detailed canvas of nigh-on 10,000 galaxies, with spirals, ellipticals and irregulars all accounted for. Those in red are some of the oldest galaxies in the universe, forming around 800 million years after the Big Bang – these only become visible to us when observing in near-infrared. The more typical spiral and elliptical galaxies are closer to us, and appear much brighter.

N159

9 SEPTEMBER 2016

Like cosmic storm clouds littered with sparkling gems, glowing gas and dark dust lanes are juxtaposed against a backdrop of blue in this region of intense star formation in the Large Magellanic Cloud, a satellite galaxy of the Milky Way. This stellar nursery is the birthplace of massive stars, which irradiate the surrounding gas. The outflow from these young stars forms hypnotising patterns in the gas and causes these clouds to emit an eerie glow, lit up by stellar radiation. This region stretches across 150 light years and lies just 180,000 light years from Earth.

MYSTIC MOUNTAIN

23 APRIL 2010

To celebrate Hubble's 20th year in orbit, the space telescope was turned towards these towering pillars of dust and gas resembling a magnificent mountain ignited with colour. Located 7,500 light years away in the Carina Nebula, each colour corresponds to the glow of a different element: oxygen is blue, sulphur is red and hydrogen and nitrogen are green. This is a very turbulent region of space, with stellar radiation constantly eating away at and moulding the mountain. Within the structure, new stars are being born from the compressed material. These juvenile stars fire off jets of gas, which are responsible for creating the wispy streamers observed at the peaks.

"It's a burst of vibrant colours and chaotic activity"

Gemma Lavender, Editor

THE VEIL NEBULA

29 MARCH 2021

10,000 years ago, a star 20 times the mass of our Sun exhausted all of its fuel and gave out in a glorious supernova explosion. This violent death sent waves of its stellar material out into the cosmos, which over time settled into the delicate filaments that make up the Veil Nebula, part of a 2,100-light-year-distant supernova remnant called the Cygnus Loop. Five different filters were used to bring out the colours of the twisting ribbons of ionised gas. This only shows a small section of the nebula; the entire loop, also catalogued as NGC 6960, measures 110,000 light years across.

AG CARINAE

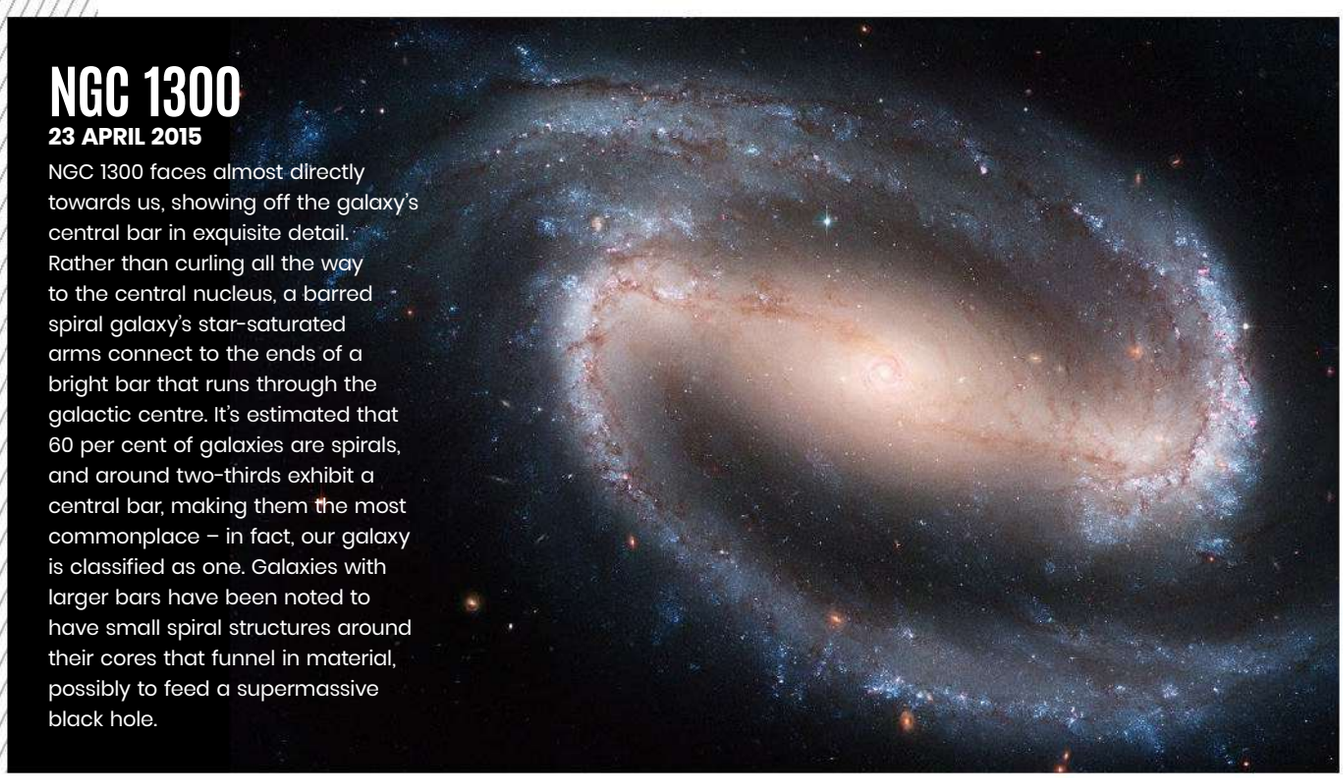
23 APRIL 2021

Though AG Carinae is one of the most luminous stars in the Milky Way, its distance of 20,000 light years means we can't really see it with the naked eye. The star is classed as a luminous blue variable due to its erratic behaviour, dimming and brightening unpredictably. Due to its unstable nature, the star is prone to eruptions. An outburst event around 10,000 years ago is believed to be the source of the ring of nebulosity surrounding the central star, suggesting that it may be struggling to hang onto its material as it approaches the end of its life.

NGC 7172

28 MARCH 2022

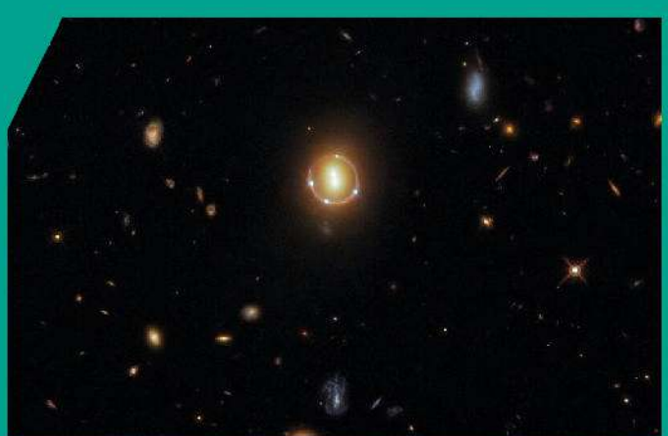
With galaxies galore in any direction you can point a space telescope, astronomers are able to view these cosmic objects from every angle to form a full picture of their structures, classifications and properties. NGC 7172 is just one of many galaxies we get a side profile of, with the spiral galaxy's edge facing towards us. The dark dust lanes obscured any secrets hidden at the galaxy's centre, but spectral analysis revealed that NGC 7172 is a Seyfert galaxy, a special class of spiral with a supermassive black hole that's currently consuming matter from its accretion disc.



NGC 1300

23 APRIL 2015

NGC 1300 faces almost directly towards us, showing off the galaxy's central bar in exquisite detail. Rather than curling all the way to the central nucleus, a barred spiral galaxy's star-saturated arms connect to the ends of a bright bar that runs through the galactic centre. It's estimated that 60 per cent of galaxies are spirals, and around two-thirds exhibit a central bar, making them the most commonplace – in fact, our galaxy is classified as one. Galaxies with larger bars have been noted to have small spiral structures around their cores that funnel in material, possibly to feed a supermassive black hole.



GRAVITATIONAL LENSING

9 AUGUST 2021

This strange ring is the light from a distant quasar being warped around two massive foreground galaxies, with these giant ellipticals acting like a magnifying lens due to a line-of-sight effect. As the quasar's light travels towards us, it passes through space-time that's curved by the influence of the massive galaxies. This bending of the light magnifies it, allowing us to see much further into the universe if a foreground object is perfectly aligned. As the foreground object in this case is a pair of galaxies, light from the quasar 2M1310-1714 is also faintly visible in the centre – an even rarer phenomenon than gravitational lensing itself.

THE BUBBLE NEBULA

21 APRIL 2016

A giant bubble measuring seven light years across is one strange sight Hubble has spotted on its universe safari. Also called NGC 7635, the shimmering sphere has been created as hot gas escaping from the massive star BD +60°2522 at over 6.4 million kilometres (4 million miles) per hour pushes against the colder interstellar gas. As the density of this gas isn't uniform, the bubble has been distorted around the star, which sits in the top left rather than the centre of the bubble. This star is 45 times more massive than the Sun and is aged at 4 million years old. It's expected to go out with a bang in the next 20 million years.

"The view of the Bubble Nebula, crafted from Wide Field Camera 3 images, reminds us that Hubble gives us a front-row seat to the awe-inspiring universe we live in"

John Grunsfeld, former NASA astronaut

© NASA

PILLARS OF CREATION

5 JANUARY 2015 AND 19 OCTOBER 2022

Possibly the most iconic Hubble target, this star-forming section of the Eagle Nebula shot to fame in a 1995 image release, making Hubble a household name. For its 25th anniversary, Hubble turned back to the imposing pillars of gas and dust, which are filled with starbirth, using its upgraded Wide Field Camera 3 to get a higher resolution view. It seemed fitting to turn Webb towards the same structure, revealing a much more star-studded view of the region. Infrared observations can peer through cosmic dust and gas to reveal what's hidden behind the haze, bringing thousands of stars into view.

STEPHAN'S QUINTET

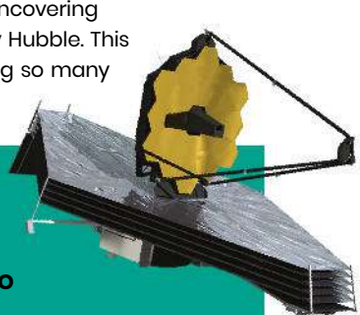
9 SEPTEMBER 2009 AND 12 JULY 2022

This grouping of galaxies is formed from four interacting galaxies and one interloper – the spiral NGC 7320 in the top left, which is 250 million light years closer to us in the same line of sight. Far beyond this forefront galaxy, a distorted spiral and elliptical sit either side of a chaotic merger. Hubble spied this cosmic collection in 2009, revealing that gravitational interactions are causing mass star formation. Over a decade later, Webb observations have given scientists a new view, resolving many more stars and clusters and illuminating the cores of the galaxies.

TARANTULA NEBULA

9 JANUARY 2014 AND 6 SEPTEMBER 2022

The Tarantula Nebula is the most active starburst region in our galactic neighbourhood, bringing new stars to life in the Large Magellanic Cloud. This image was put together using data from the Hubble Tarantula Treasury Project (HTTP), an effort to map out and study the region's stellar population in order to surmise its overall structure. Webb's advanced eyes were able to reveal even more detail in the swirling wisps of dust and gas, as well as uncovering thousands of stars and background galaxies unseen by Hubble. This region is a favourite for studying stellar evolution, hosting so many stars of different ages and sizes.



A WORTHY SUCCESSOR

The James Webb Space Telescope is by no means a replacement for Hubble

After several delays, Webb was launched into space on 25 December 2021, set to make the 1.5-million-kilometre (930,000-mile) journey to its orbital outpost at Lagrange point L2 before opening its eyes to the universe. Conceptualised as the Next Generation Space Telescope in 1996 – when Hubble was still in its infancy – it was never intended to usurp its predecessor, but instead achieve what the original space telescope couldn't. While Hubble does possess some infrared capabilities, its instruments weren't designed for these types of observations, focusing on visible and ultraviolet wavelengths. Webb was created to look beyond Hubble in the infrared, allowing it to view more distant objects with higher redshift. Though both telescopes have a similar purpose, each is able to see the universe in a different light, bringing more of the electromagnetic spectrum into view.

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IS JUPITER PROTECTING US?

Earth has good reason to be grateful to the king of the Solar System, though its influence isn't always benign

Reported by Andrew May

Jupiter is by far the largest planet in the Solar System, containing more than twice as much mass as the rest of the planets put together. As such, its influence on the dynamics of the Solar System is second only to the Sun itself, and it's often said that Jupiter is the planetary 'protector' of Earth. But is that true, and if so, how does it work? To start with, Jupiter isn't really that close to us. The distance from Earth to the Sun is one astronomical unit (AU), while that between the Sun and Jupiter is much bigger at around 5.2 AU. This means that Jupiter never gets closer to us than 4.2 AU, and it's often much further away than that. And as big as Jupiter is, it still only has a thousandth of the Sun's mass, so its direct gravitational effect on us is negligible in comparison.

The reality is that Jupiter's influence on Earth isn't direct, but comes about via its effect on much smaller objects in the Solar System, all the way from asteroids down to grains of dust. Continuously through its 4.6 billion years of existence, Jupiter has helped to shape the Solar System through its gravitational effects. As far as Earth is concerned, we can thank Jupiter for protecting our planet from devastating collisions in the period immediately after its birth and then giving it enough water to fill the oceans. Then it tidied up the surrounding environment by sweeping up a large

© NASA

proportion of the rocky debris left over from planet formation, and even today it continues to shepherd incoming comets away from the inner Solar System.

To look at all of that in a little more detail, we need to go right back to the dawn of the Solar System. According to current theories – based largely on computer modelling – it's quite possible that Earth wouldn't exist at all if wasn't for Jupiter. One view that's popular with astronomers is the so-called 'grand tack' model, originating from 2011. The name comes from a sailing analogy, as one of its originators, Kevin Walsh of the Southwest Research Institute in Boulder, Colorado, explained at the time: "We refer to Jupiter's path as the grand tack because the big theme in this work is Jupiter migrating towards the Sun and then stopping, turning around and migrating back outwards. This change in direction is like the course that a sailboat takes when it tacks around a buoy."

In the grand tack hypothesis, Jupiter was the first planet to form, but it did so significantly closer to the Sun than it is today, at about two-thirds of its present distance. Then, almost immediately, its orbit started to change. The entire space around the Sun was still filled with a relatively dense disc of gas and dust that sapped energy from the newly created planet through a process analogous to aerodynamic drag. This caused Jupiter to spiral into an even smaller orbit, only stopping after the formation of a second planet, Saturn. Orbiting further out than Jupiter, Saturn pulled it back outwards until Jupiter ended up close to its present position. This whole process took around half a million years – a very short period by astronomical standards – and was over before Earth and its neighbouring inner planets had even begun to form. But their destinies had been sealed. Jupiter's inward plunge pushed large quantities of rocky debris, which might otherwise have coalesced into a gigantic inner planet, into the Sun. This left just enough material to make Mercury, Venus, Mars and Earth – the latter at just the right distance from the Sun to provide surface temperatures in the narrow range where the development of life was possible.

Of course, the emergence of life on Earth required other factors besides the

"As far as Earth is concerned, we can thank Jupiter for protecting our planet from devastating collisions"

JUPITER AND THE ASTEROID BELT

If the Solar System had evolved slightly differently, life on Earth might not exist

1 Disrupted asteroid belt

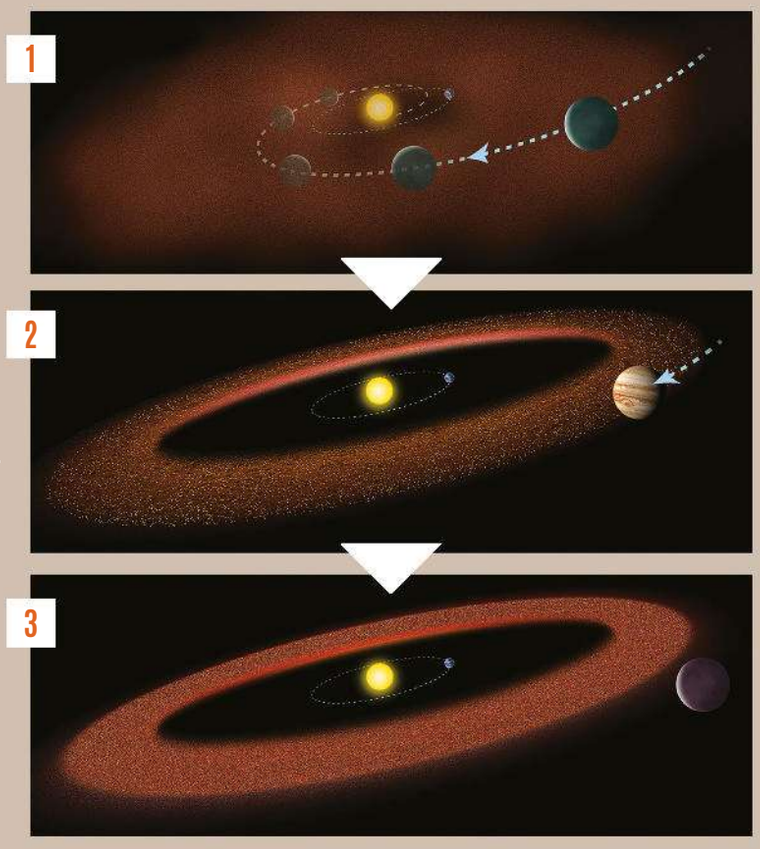
If Jupiter's inward migration had continued all the way through the asteroid belt, it would have disrupted Earth's development so much that it would probably have prevented the emergence of life here.

2 Solar System asteroid belt

This shows what actually happened in the Solar System. Although Jupiter did migrate inwards, it stopped outside the main asteroid belt. This allowed the planets further in – Mars, Earth and Venus – to remain stable and undisrupted.

3 Dense asteroid Belt

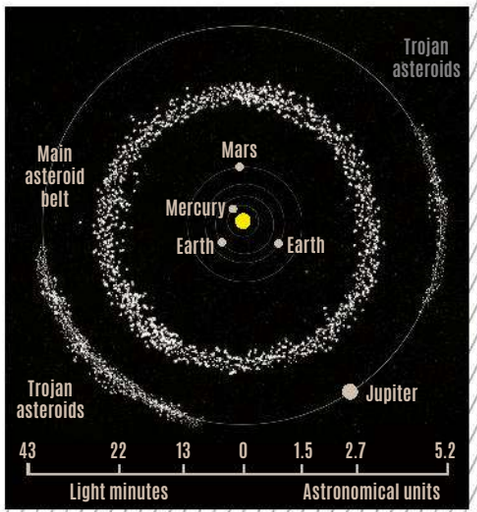
If Jupiter hadn't migrated inwards at all, far more asteroids would have survived to form a much denser belt. Constant bombardment of the inner planets by these asteroids would probably have prevented life from evolving.



WHY WE NEED COMPUTER MODELS

There's no simple solution to the interaction of three or more bodies

The motion of one body orbiting another, such as a lone planet around a star, has an exact mathematical solution. But that's not true if other gravitational effects are involved, such as the influence of Jupiter on the orbit of an asteroid. A few stable solutions can be found algebraically, such as the existence of the 'trojan points' in the orbit of Jupiter itself, but more general solutions require computer modelling on a case-by-case basis. These solutions are not always stable – they may change slowly over the course of many orbits. For example, Jupiter can disturb the orbit of an asteroid that initially comes nowhere near an inner planet into one that poses a collision threat to it.

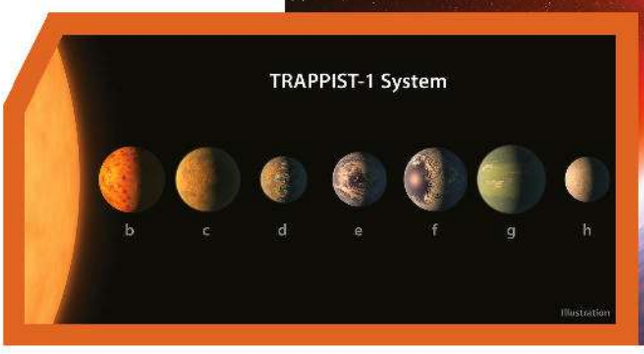


Some systems, such as TRAPPIST-1, contain no Jupiter-sized planets

Jupiter may actually increase the chances of an asteroid colliding with Earth

right temperature – perhaps the most important of them being copious amounts of surface water. And it's likely we have Jupiter to thank for this, too. If we're going to call that giant planet our 'protector', it's at this point the concept becomes a little less straightforward. Not too long after the formation of Earth and its rocky neighbours, Jupiter's gravity caused the small planets to be inundated with a heavy rain of debris that it diverted inwards from the outskirts of the Solar System. This might not sound much like protection, but it was certainly a benevolent act from our point of view. That debris consisted largely of ice rather than rock, and it's where most of Earth's water came from.

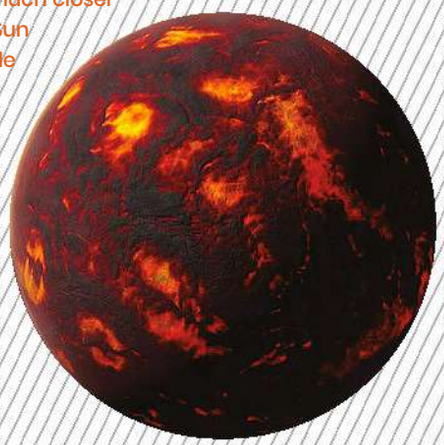
From our point of view, this may be Jupiter's most important role in our past, and something that could happen in any system with a massive Jupiter-like planet orbiting out beyond rocky inner planets. As David O'Brien of the Planetary Science Institute said in 2018: "I think the coolest thing is that it basically implies for any exosolar system where you

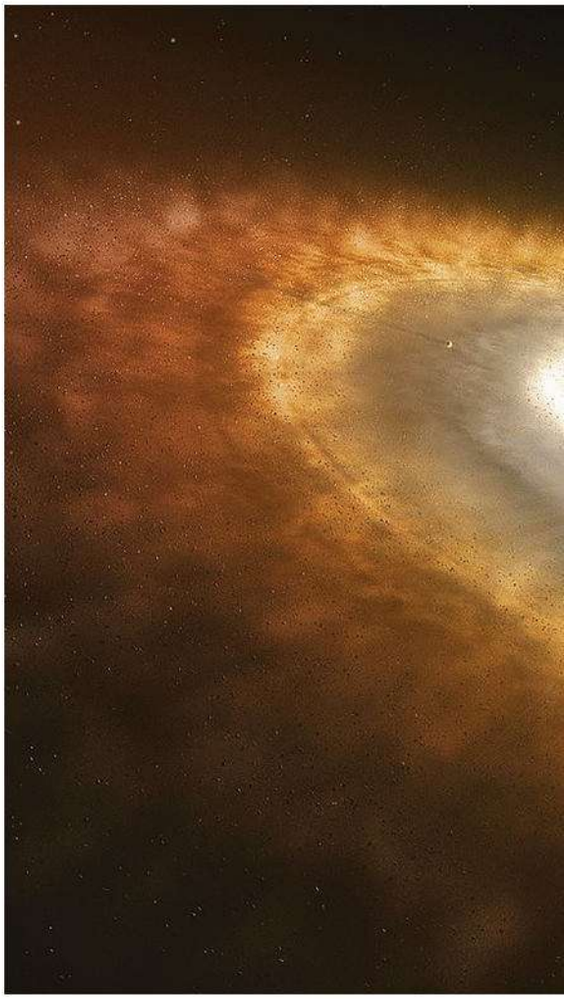


OTHER PLANETARY SYSTEMS

Astronomers have observed many systems without a Jupiter equivalent, and they don't have an Earth either

It's tempting to think that our Solar System is typical, with the giant planet Jupiter relatively far from the host star, while Earth and other rocky planets are further in, and nothing is closer to the Sun than Mercury. But as NASA researcher Yasuhiro Hasegawa observed in 2020, "that kind of configuration currently seems very rare". In fact, many exoplanet systems seem to lack anything resembling Jupiter, while so called super-Earths – planets larger than Earth that are much closer to their star than Mercury is to the Sun – appear quite common. It's possible that such a super-Earth did start to form early in the life of the Solar System, but was then pulled to pieces by Jupiter's gravity during the grand tack, with most of the debris falling into the Sun. This left just enough material for Earth to form, so it's yet another reason for us to be grateful to Jupiter.





Artist's impression of a newly formed star surrounded by a dusty disc prior to planet formation

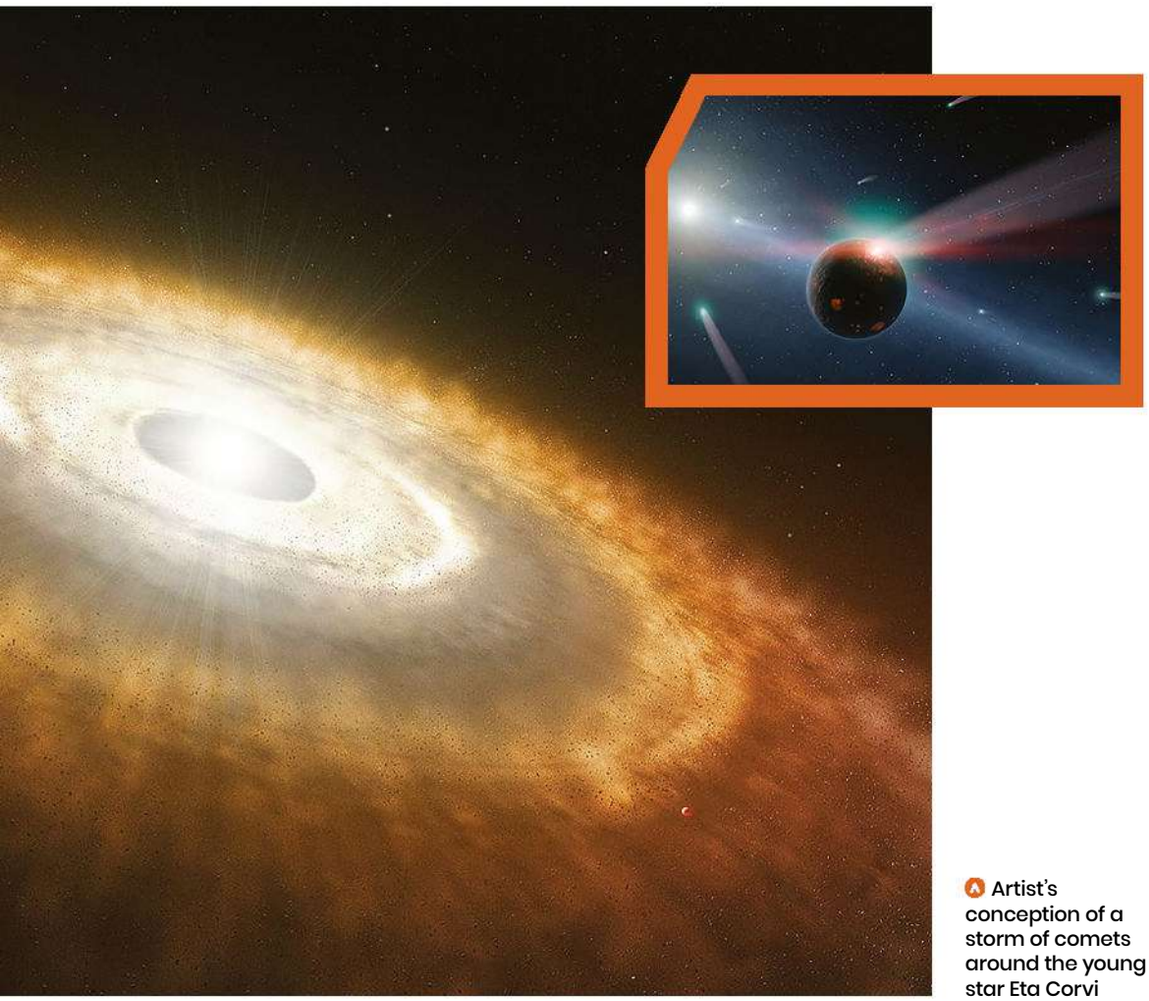
have giant planets and terrestrial planets, those giant planets would send water inward to the terrestrial planets." As far as the Solar System is concerned, these large-scale cometary bombardments lie billions of years in the past, but there is evidence that similar things are happening in younger planetary systems today. In 2022, for example, NASA reported observations by its Spitzer Space Telescope that appear to show an ongoing comet storm around the young star Eta Corvi.

In our Solar System, Jupiter has shepherded most of the remaining protoplanetary debris into a neat ring – the asteroid belt – between its own orbit and that of Mars. This contains over a million objects that are large enough to be seen through telescopes from Earth, but most of them are little more than boulder-sized, with a combined mass less than that of Earth's Moon.

As far as Earth is concerned, Jupiter's role today is pretty much a 50:50 balance between protective and destructive. In the latter category, Jupiter's gravity can sometimes nudge an asteroid out of its neat orbit in the asteroid belt and cause it to fall inwards towards the Sun, where there's a chance – though not necessarily a big one – that it might collide with Earth. On the other side of the scale, Jupiter's most protective effect relates to so-called long-period comets, which fall in from the Oort Cloud that lies on the outermost periphery of the Solar System. These are often much larger than the more familiar short-period comets, and generally travel at very high speeds when they arrive. They're potentially pretty dangerous, but fortunately Jupiter's gravity tends to swing most of them back out of the Solar System before they get anywhere near Earth. Without Jupiter acting as gatekeeper in this way, it's likely that long-period comets would hit Earth much more frequently than they do.

So is Jupiter Earth's protector or not? If we take a narrow view at the present time it's not an easy question to answer, though it seems to be doing a reasonably good job of keeping us out of harm's way. But if we take a longer look, all the way back to the very beginnings of the Solar System, we can safely say we wouldn't be here at all if it wasn't for Jupiter.

Andrew May
Space science writer
Andrew has a PhD in astrophysics and 30 years in public and private industry. He enjoys space writing and is the author of several books.



Artist's conception of a storm of comets around the young star Eta Corvi

JUPITER AND COMETS

Jupiter can change orbits, making a comet either more or less likely to hit Earth

As comets fall inwards towards the Sun on highly elongated orbits, they may feel enough of a pull from Jupiter's gravity to alter their course significantly. This has happened several times to comet 67P/Churyumov–Gerasimenko, best known as the destination of the Rosetta mission in 2014. Over the course of multiple orbits between 1840 and 1959, its closest approach to the Sun gradually reduced from 4.0 to 1.3 AU – the latter close enough to Earth's own orbit to be worrying if the inward trend resumes in future. But Jupiter can also have a protective effect by swallowing up comets that get too close to it, as was seen in dramatic fashion in 1994 when the fragments of Comet Shoemaker-Levy 9, already broken apart by Jupiter's gravity, crashed one after another into the giant planet.

JUPITER THE DESTROYER?

As beneficial as Jupiter is to Earth, it also has a destructive side

Using computer simulations, Dr Jonti Horner of the University of Southern Queensland in Australia examined how the presence of Jupiter affects the rate of impacts on Earth for three different types of objects: asteroids, short-period comets and long-period comets. He found that only in the last case was Jupiter's effect unambiguously beneficial. For asteroids and short-period comets, on the other hand, Jupiter's presence appeared to increase the collision rate. However, this was relative to the complete absence of a planet-sized object in Jupiter's orbit, which isn't necessarily realistic. In models where there is a planet there, but significantly smaller than the real Jupiter, the rate of collisions turned out to be enormous. Jupiter may not be the best-case scenario, but it's not the worst either.

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FOCUS ON

EARTH SPOUTS 'BIOSIGNATURES' INTO SPACE, HINTING THAT OTHER LIFE-BEARING WORLDS MAY DO THE SAME

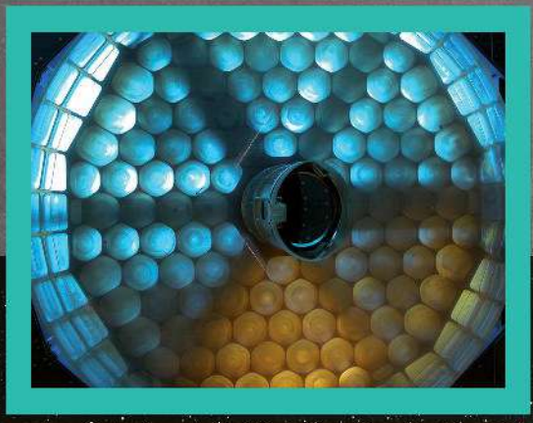
An unusual form of oxygen produced by plants and bacteria has been found above our planet's

Reported by Tereza Pultarova

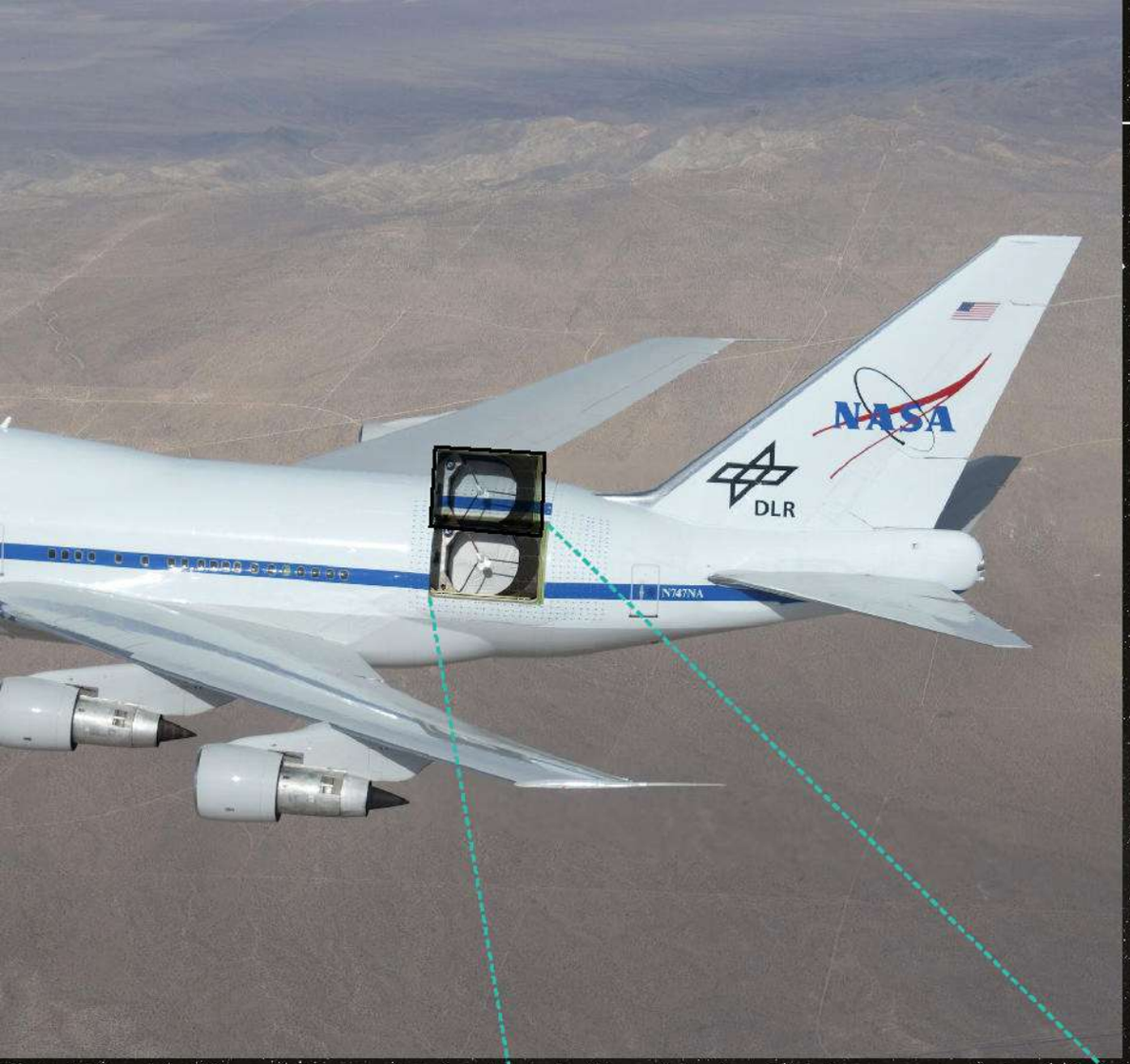
A new study has revealed that forms of oxygen created by living organisms can be found in space around our planet, hinting at a potential new method for tracing life on other habitable planets in our galaxy. The discovery was made by NASA's now-retired Stratospheric Observatory for Infrared Astronomy (SOFIA), a flying telescope mounted on an adapted Boeing 747. A recently published study describes how researchers used the telescope, which is sensitive to warmth-carrying infrared wavelengths of light, to detect so-called heavy atomic oxygen in the upper layers of Earth's atmosphere – the mesosphere and lower thermosphere. Heavy oxygen is a form of oxygen that has ten neutrons in its nucleus, compared to the eight seen in the most widespread form of oxygen present in the air around our planet. High concentrations of heavy oxygen can be found close to Earth's surface, as this atomic specimen is commonly produced by photosynthetic organisms.

"It's tracing biological activity – that's well proven," Helmut Wiesemeyer, a scientist at the Max Planck Institute for Radio Astronomy in Germany and lead scientist of the new study, said. "So far, the altitude to which this signature extends was thought to be 60 kilometres [37 miles], so barely the lower part of the mesosphere." However, according to the new study, SOFIA was able to detect heavy oxygen up to 200 kilometres (120 miles) above our planet at concentrations that suggest earthly origins.

Heavy oxygen can also come from the solar wind, the stream of particles constantly emanating from the Sun's atmosphere. The concentrations of solar heavy oxygen, however, are believed to be much lower. "The question was, does it reach higher altitudes? And if it does, because there are no living organisms up there, the only way to reach higher altitudes would be an efficient vertical mixing [of air in Earth's atmosphere]," Wiesemeyer said. The findings may have potential implications for the



SOFIA's mirror is made from a glass ceramic material called Zerodur.



INSIDE SOFIA

1 Primary mirror
A 2.7-metre (8.9-foot) parabolic reflector.

2 Secondary mirror
This sends light from the primary to the tertiary mirror.

3 Forward bulkhead
Isolates the telescope from the rest of the aircraft fuselage.

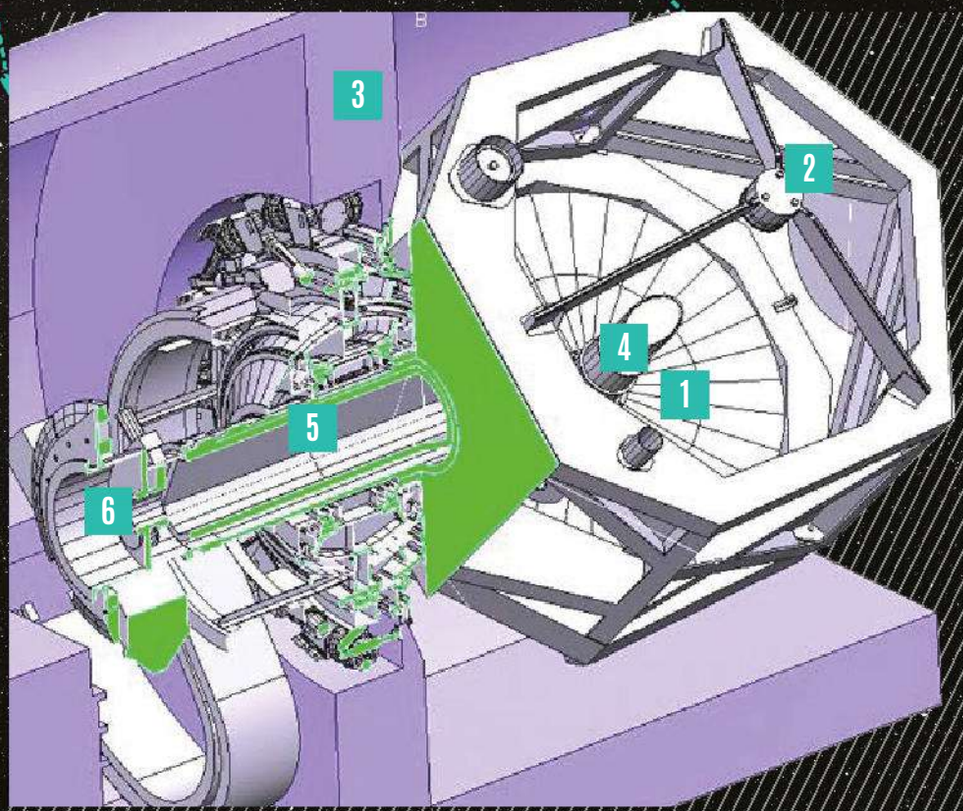
4 Tertiary mirror
This sends light into the Nasmyth tube.

5 Nasmyth tube
This carries light from the tertiary mirror to the focal point.

6 Focal point
This is where the scientific instruments inside the aircraft collect and record data.

development of new techniques for the detection of markers of life around exoplanets, planets orbiting other stars than our Sun. "The idea is to first understand what happens in front of your own door before you go into deeper studies elsewhere," Wiesemeyer adds.

The presence of 'made-on-Earth' heavy oxygen so high above the planet also suggests that air must be mixing with great efficiency throughout the layers of the atmosphere, something that researchers want to study further to better understand Earth's system. The discovery may also have implications for climate change research, Wiesemeyer added. Researchers are keeping an open mind to other possible explanations of heavy oxygen so high above the planet, but if the discovery is confirmed, it would mean that Earth's biological influence spreads much farther into space than scientists previously thought.



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MYSTERIES OF THE UNIVERSE

IS THE MOON WITH THE PLUMES HOME TO LIFE?

Scientists think they've found a way to work out if there's microbial alien life on Enceladus without plunging into its liquid ocean

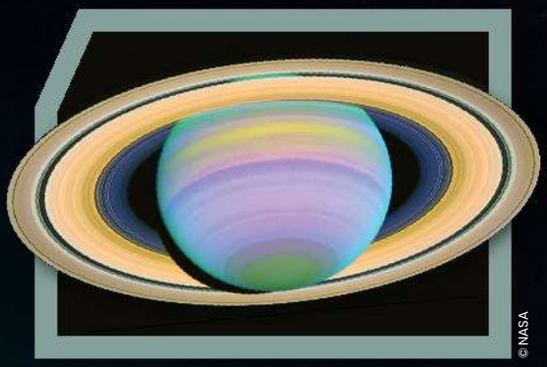
Reported by David Crookes

Enceladus was once considered to be of little interest to astronomers. As one of 83 known moons of Saturn and just 500 kilometres (310 miles) in diameter, this cold, tiny world orbiting its gas giant host every 33 hours was largely overlooked as time-pressured astronomers focused their attention on other celestial bodies. It's hard to blame them for doing so. Enceladus, discovered by William Herschel in 1789, had been visited by the two Voyager spacecraft, Voyager 1 and Voyager 2, in 1980 and 1981. Those flybys got as close as 90,000 kilometres (56,000 miles) from the moon's surface, but they didn't appear to find anything remarkable.

Instead it seemed as though Enceladus was simply frigid and inactive – a small stark-white dot covered in water ice reflecting all of the sunlight striking it from far away. But as time went on, more and more astronomers began to take notice of this moon. "People were suspecting that something about Enceladus was off," affirms Dr Antonin Affholder, a postdoctoral research associate at the University of Arizona. "It seemed that the E ring of Saturn was somehow made out of material that comes out of Enceladus."

Astronomers suspected that the moon may have been struck by meteors or that ice volcanoes were spewing material into Saturn's E ring – the one which is much wider than any of the others. But NASA's Cassini research mission prompted astronomers to change their minds. Cassini found plumes shooting from the surface of the moon at its south polar region, expelling water vapour and tiny grains of ice. It was something of a game changer. There had been a buildup to this moment. When Cassini was flown within 175 kilometres (100 miles) of Enceladus' surface, for example, astronomers saw a surface pretty much free of craters, and that ruled out recent meteor impacts. There was also an absence of ice volcanoes. The moon's south pole was warmer than its equator, too, while an area around four linear fractures – called the 'tiger stripes' – was even warmer. There was a water cloud above Enceladus in this location as well, and it soon transpired that the moon had reservoirs of warm water beneath its surface. The water, it transpired, was likely making its way up and out as plumes. Subsequent flybys would discover even more.

As well as imaging the plumes, Cassini flew straight through them in March 2008 at an altitude of 200 kilometres (120 miles). The craft found that the plumes were ejecting water vapour, carbon dioxide, carbon monoxide and organic materials


© NASA

A The plumes appear to be feeding Saturn's E ring, the second outermost of the planet's rings

at high densities at 1,300 kilometres (800 miles) per hour. Temperatures here were found to be even warmer.

"Data acquired by the Cassini mission suggested that a liquid water ocean and hydrothermal circulation are likely under Enceladus' ice crust," says Affholder. "Moreover, Cassini found molecules that are either food sources or waste of hydrothermal vent-based ecosystems on Earth." This latter discovery caused Affholder to think. Together with Régis Ferrière, senior author of the new paper and associate professor in the University of Arizona's Department of Ecology and Evolutionary Biology, he and a team began to explore the possibility of life on Enceladus and the best way of working out whether it exists there.

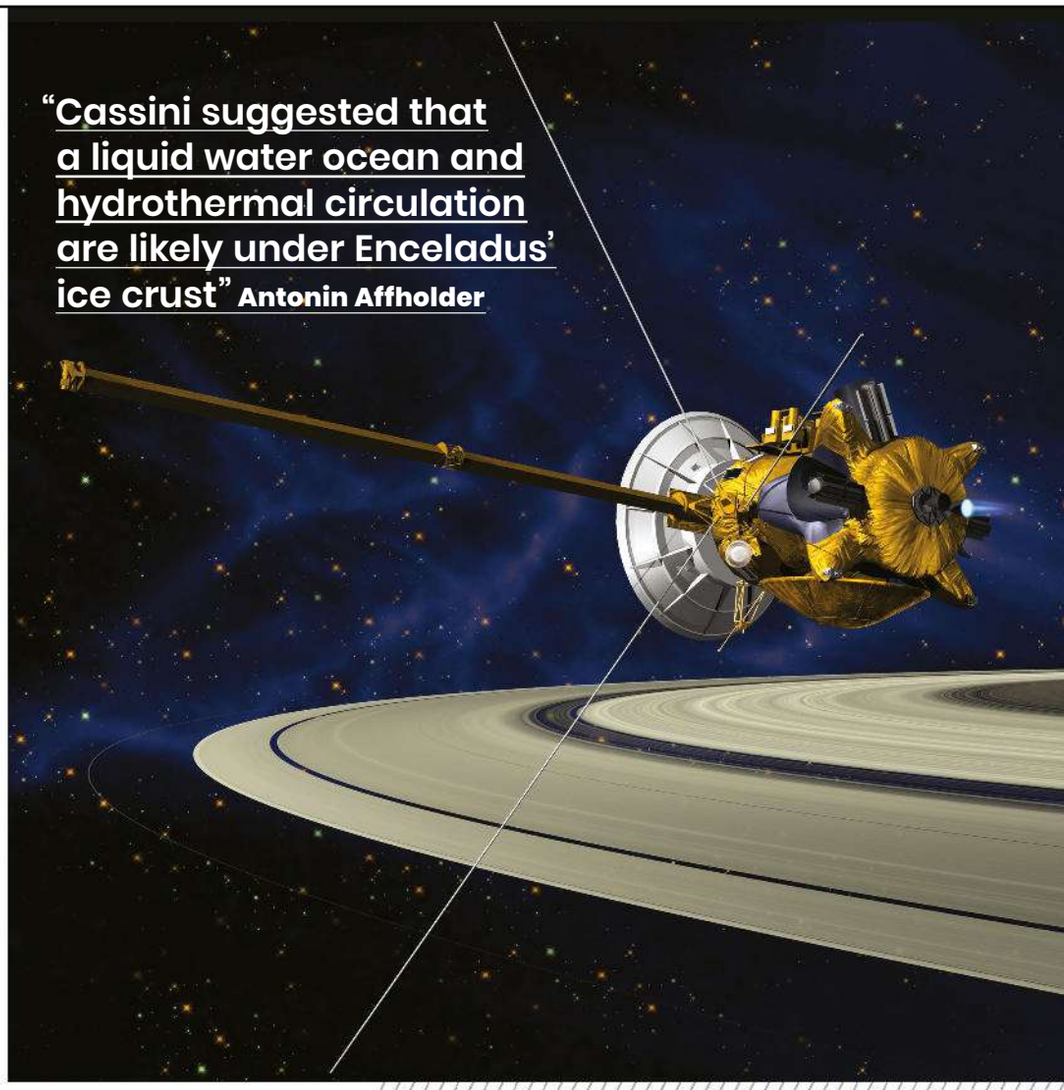
Discovering the outgassing of methane from a warm, saltwater ocean was crucial to this work. Here on Earth, methane typically originates from microbial life. Finding evidence of methane in the plumes – along with other organic molecules that build the foundations of life – became the catalyst for their study. "The question became: does the quantity of dihydrogen and methane found in the plume match the expected consumption or production by a hydrothermal population?" Affholder asks. "We thought that, as biologists, we could chime in and actually crunch the numbers to understand which scenario was more likely – that plume-found methane came from microbes, or that it came from its spontaneous synthesis in hydrothermal fluids."

An initial study in 2021 analysed Cassini's plume data using mathematical models that combined geochemistry and microbial ecology. "There wasn't a whole lot being said about the methane in the plume," Affholder tells **All About Space**. "I think that other scientists were definitely open to explore the idea that Enceladus' methane could be produced by a biosphere, but generally, I think that the non-biological source that people had in mind was the synthesis of methane that occurs spontaneously in hydrothermal fluids."

Ferrière and his team found that the methane concentration measured in the plumes could not be entirely explained by known hydrothermal chemistry. For the detected levels to be present, they concluded that biological methanogenesis would need to be added to the mix. To explain, the scientists point to the dark, highly pressured hydrothermal vents on Earth which nevertheless teem with life. The simplest of the creatures are microbes called methanogens, which convert dihydrogen and carbon dioxide to gain energy and release methane.

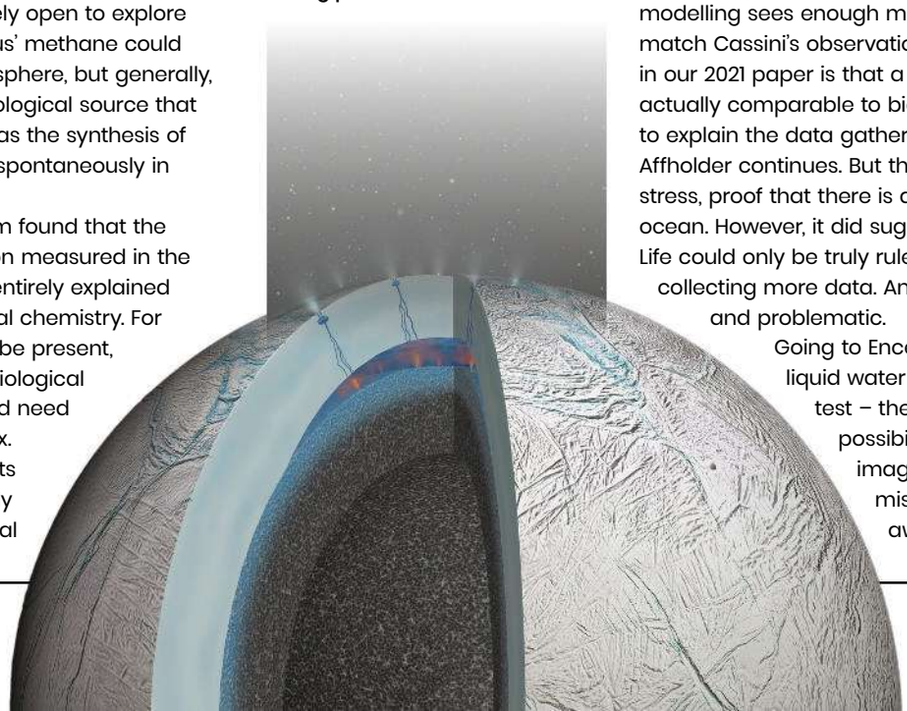
Adding methanogens into the mix while computer modelling sees enough methane being produced to match Cassini's observations. "What we have shown in our 2021 paper is that a non-biological source isn't actually comparable to biological production, and it fails to explain the data gathered by the Cassini mission," Affholder continues. But this wasn't, the researchers stress, proof that there is definitely life in Enceladus' ocean. However, it did suggest that it was probable. Life could only be truly ruled out – or indeed in – by collecting more data. And yet missions are expensive and problematic.

Going to Enceladus and plunging into the liquid water would be the most ideal test – there would even be a remote possibility of taking conclusive images – but given that such a mission could be many years away, the scientists worked

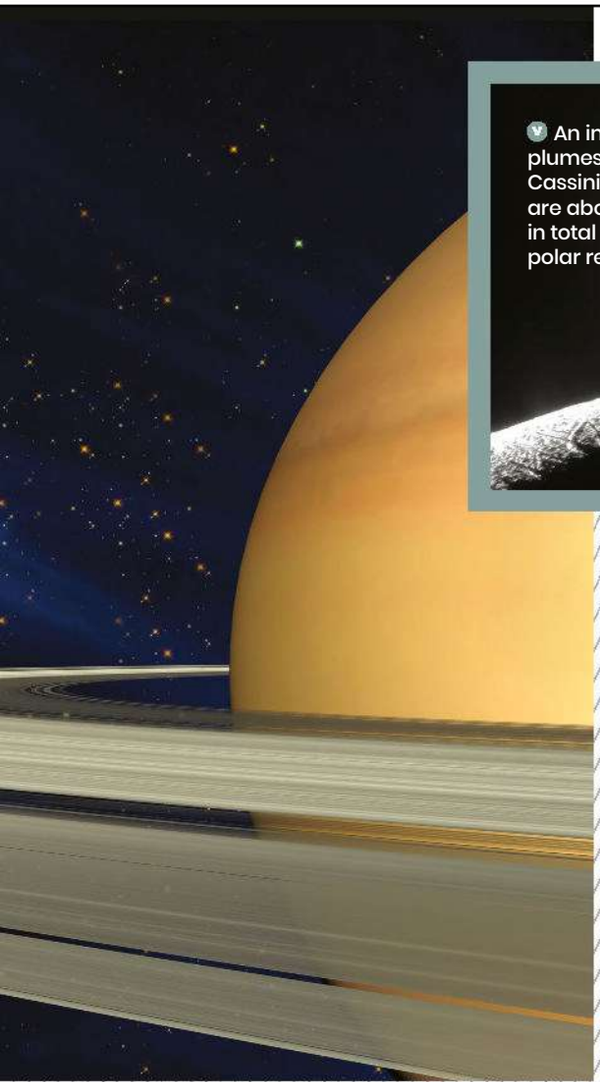


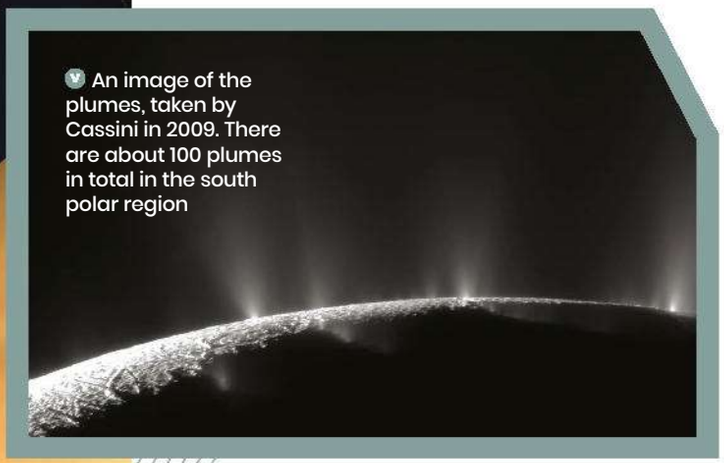
"Cassini suggested that a liquid water ocean and hydrothermal circulation are likely under Enceladus' ice crust" Antonin Affholder

Cassini revealed many secrets about Enceladus, but the existence of life there remains inconclusive



A cutaway of Enceladus showing how hydrothermal activity could be taking place





An image of the plumes, taken by Cassini in 2009. There are about 100 plumes in total in the south polar region

on an alternative. "Searching for such microbes, known as methanogens, at Enceladus' seafloor would require extremely challenging deep-dive missions that are not in sight for several decades," Ferrière says. One thing was certain, though: the possibility of life on the moon couldn't be left dangling. "My conclusion from this 2021 study is that, given the Cassini data, the possibility of the existence of life in Enceladus' ocean is definitely worth exploring," Affholder says. "I think it's better to look at it this way: it's not that life is more likely, it's that current non-life explanations are less likely, and that life is not unlikely given the current data. It's convoluted, but it's important to understand that this study doesn't constitute positive evidence for life, but just a failed attempt at disproving its existence."

To that end, the team believes they have a method capable of clearing up the

ENCELADUS BY NUMBERS

83
Enceladus is one of Saturn's 83 known moons

1789
Year it was discovered

1980
Year NASA's Voyager 1 surveyed it

2005
Cassini began multiple flybys in this year

500
Diameter in kilometres

680
times less mass than

210
Surface temperature of Enceladus in degrees Celsius

800
Its ice shell may be as thin as 800 metres

TEN KILOMETRES
How deep Enceladus' ocean is thought to be

THREE WAYS TO EXPLORE THE PLUMES

Scientists have a few options for determining if life is present on Enceladus

Perform a deep dive

In 2015, NASA's Cassini spacecraft plunged deep into Enceladus' plume. It measured hydrogen within the jets of ice and dust by cruising 49 kilometres (30 miles) above the small moon's south pole. The next step for a spacecraft could be a deep dive through Enceladus' ice cracks towards the seafloor. That would be ideal, but extremely expensive and difficult.

Use a powerful telescope

The James Webb Space Telescope can use its infrared capabilities to study Enceladus, and the moon is on the list of bodies to look at. Webb can study the molecular composition of the plumes, and it could also search for organic signatures such as methane, methanol and ethane. But a research team's time with Webb will need to coincide with a rich emission.

Sample the plumes again

The latest thinking believes another dive into the plumes by a different spacecraft is all that's required. The aim would be to pack the craft with upgraded instruments, and so long as it collects a minimum recommended amount of material, that would provide sufficient data. This method could also park a probe on the moon's surface.

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EASING THROUGH THE CRACKS

How plumes are understood to be formed on Enceladus

1 Liquid water

Enceladus has a large volume of liquid salty water beneath its crust, and it's only a few kilometres from the surface. Recently, scientists have discovered an ice variant called medium-density amorphous ice that's almost as dense as water – perhaps this makes up the ocean.

2 Creating currents

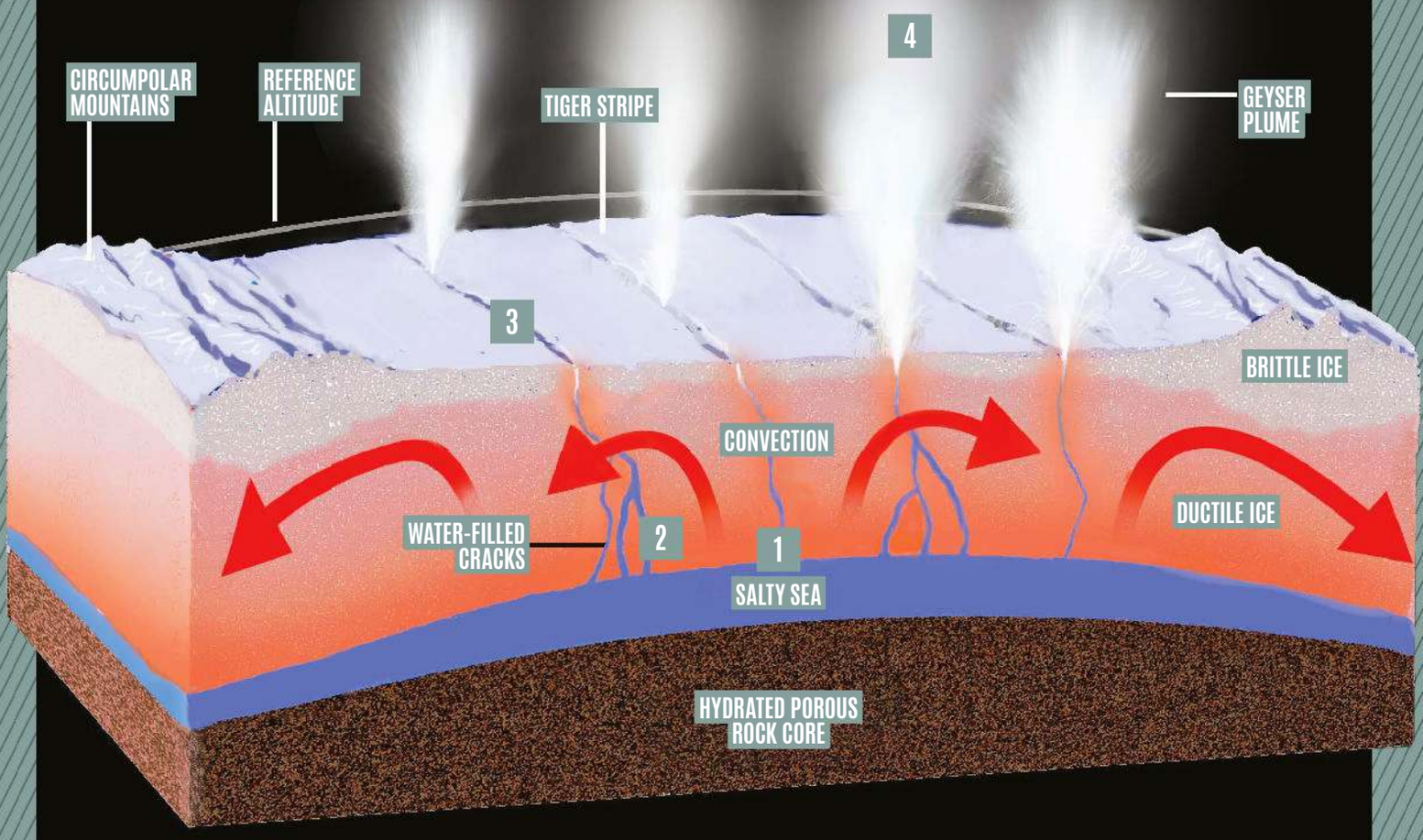
Enceladus is subjected to the strong gravity of Saturn, and it puts the moon's liquid water under pressure. Internal heating generates vertical convection currents and causes the water to fill cracks in the ice layer.

3 Tiger stripes

There are four sub-parallel linear depressions on the moon. These are in the south polar region. They allow the icy particles to continue upwards and out. The surrounding ridges are covered in coarse-grained crystalline water ice. Fine-grained water ice is found elsewhere on Enceladus.

4 Producing the plumes

Water vapour and small grains of ice shoot into space. Cassini data shows it also contains molecular hydrogen, methane, carbon dioxide and rock fragments. A faint E ring is created that traces the orbit of the moon around Saturn.



"Definitive, irrefutable proof would be to bring a microbe back to Earth. But that is a costly, ambitious mission"

Antonin Affholder

The Cassini spacecraft flew through Enceladus' plumes and detected their content

mystery suggested by the moon's plume. Their study concludes that another visit by an orbiting spacecraft is all that would be needed. This would be effective despite the team expecting there to be only a small mass of microbes living in Enceladus' ocean – the hypothetical abundance of cells would only amount to the biomass of a single whale in Enceladus' global ocean. "We didn't have many expectations before running the calculations," Affholder continues. "As is often the case with models, they make us say 'duh' once we see the results. Maybe the most important factor in determining the population size is the overall scale of the hydrothermal environment. Enceladus is tiny – as wide as Arizona – hence any biosphere that could be present there is necessarily smaller than Earth's.

"Then there's the food source. The bulk of the 'standing' biomass on Earth [the biomass present in living form at any given time] is made out of trees. Their ability to store carbon in their trunks makes them a formidable reservoir. More generally, most of Earth's biomass is found in photosynthetic organisms. They are in no shortage of energy; the Sun rises every day, and with carbon, there's plenty in the atmosphere for them to absorb. But methanogens are different. They operate on a scarce and low-yield food source found in the chemical disequilibrium that the abundance of dihydrogen and carbon dioxide generated in some places. In our model, we assumed that the population at Enceladus' seafloor would be exclusively composed of those methanogens. Small environment, low-yield organisms make for small populations."

The big difference between Cassini and their proposed new mission, detailed in a paper published in the *Planetary Science Journal*, is that a fresh spacecraft would be sent fully prepared to detect life. When faced with a fully equipped probe, Affholder says the moon's biosphere would prove productive enough to feed the plumes with sufficient organic molecules or cells to be picked up by a future spacecraft's onboard instruments. "Cassini could mainly detect and quantify smaller molecules [volatiles]," he explains. "But life also synthesises bigger molecules [organics]. We don't know exactly what big molecules early or alien life would use or synthesise. But there's a good chance that smaller organics used by Earth's life and alien life are similar because they are found in very different places and can be synthesised spontaneously. A new mission focused on those organics could help."

The scientists have detailed the minimum amount of material that would need to be collected from the plumes in order for the hypothetical mission to be successful. They suggest looking for amino acids – the presence of which would be indirect evidence for life – rather than actual cells, since the likelihood of the latter surviving being thrown into the air by plumes erupting from the surface is arguably slim. The emphasis, the team says, would be on working out not what minimum amount of organic material would be sufficient for a reasonable conclusion of life, but what maximum amount of organic material would be sufficient to conclude there's an absence of life. So what is the team hoping for? "The discovery of alien life would be an extraordinary scientific milestone," says Affholder. "As such, there cannot be anything less than extreme evidence for scientists to be confident that life exists in Enceladus' ocean.

"Does a suspiciously high quantity of methane constitute extreme evidence? No. Definitive, irrefutable proof would be to bring a microbe back to Earth. But that is a costly, ambitious mission. Not only is it beyond our technical skills, we would need to have high prior confidence before throwing everything that we have at such a focused mission. In the meantime, what broader spectrum mission would increase or decrease our confidence in the existence of life at Enceladus' seafloor? This is what we have been trying to explore in our newer study." It may just be that their theory one day soon becomes reality.

David Crookes
Science and technology journalist
David has been reporting on space, science and technology for many years, has contributed to many books and is a producer for BBC Radio 5 Live.

© NASA, JPL-Caltech

STARS

Would any Earth-based observers have been able to see Scholz's star?

Personally, I think not. The star is much fainter than you would expect to see with the naked eye. Even if Proxima Centauri – our closest red dwarf, which is a bit hotter than Scholz's star – came as close to us as Scholz's star did, you still wouldn't be able to see it with the naked eye. By the naked eye, it's harder to see because it would be at 11th magnitude. And we can see stars only up to sixth magnitude with the naked eye.

Nonetheless, Scholz's star is a strong flare star, and outbursts from their surfaces can be very strong. Flare stars can reach up to seventh or eighth magnitude, so in that case it could be visible, but who would notice? If Scholz's star was still on the boundary of sixth magnitude at normal times it would be easier to observe with the naked eye. There was no pollution 70,000 years ago; Earth had clear skies and you could see more stars in the Milky Way and very clearly in the sky.

Ralf-Dieter Scholz, astronomer at the Leibniz Institute for Astrophysics Potsdam in Germany, where he discovered Scholz's star, a red dwarf with a brown dwarf companion

© Michael Osadciw / University of Rochester, Getty Images

COSMOLOGY

How has cosmology developed the discovery of the cosmic microwave background?

As the Big Bang was fleshed out, there were a couple of nagging problems. One is the density problem. If you start off with just the right density so that space is flat, it will continue at that density as everything expands. If you change it by even the tiniest amount, the expansion will go on for a short time and then collapse. If you take away one part the expansion will go so fast that stars won't form, and we would never be here. The other problem is the uniformity. If we look in different directions we see essentially the same thing. And yet in the standard Big Bang, the regions where the radiation came from had never been in direct contact.

In 1980 Alan Guth proposed his cosmic inflation theory. Inflation takes a tiny little space and grows exponentially in a very short time so that the density will be just right. Inflation also invokes quantum fluctuations to seed the structure of our universe. Inflation starts the whole thing going, the universe expands for 380,000 years, and that's where the cosmic microwave background originated. Expansion continues, and after a while there are stars. 13.8 billion years later, here we are, trying to understand our universe. So it kind of looks like we understand what is happening.

Robert Woodrow Wilson, an American radio astronomer who, alongside Arno Penzias, won the Nobel Prize in Physics for the discovery of the CMB

SOLAR SYSTEM

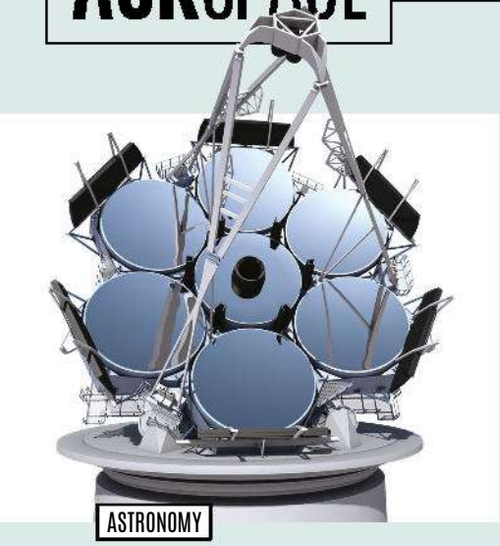
Why do we have to look at asteroids in space rather than on Earth?

We have already learned so much from meteorite analysis. Meteorites bombard us every day, and we've collected thousands of meteorites on Earth. People spend time studying meteorites in every single detail in laboratories, and they're available in a much larger amount – not just tiny specks, but large rocks of meteorites – so you've got a lot more material to study. If you want to look at things like water and organics, it's better to have a lot more organic material to study, because they don't really come in large amounts, so you usually need to concentrate on them to be able to study them.

We have learnt so much about organics and water from meteorite studies in the past, but there is one problem – all meteorites are recovered on Earth. Some are recovered as what we call a 'find meteorite', so we have found them on an exploration to Antarctica, for example, and you don't know how long they've been residing in the ice. Most of our samples are recovered from expeditions from Antarctica, but as they've been sitting in the ice water for a long time, you don't know how much terrestrial contamination they have been exposed to. It's essential that we know what is contaminated and what is not, and it's a challenge to do that. Some meteorites are recovered as 'fall meteorites', so people see when and where they fell and go and collect them as soon as they can. But even in these scenarios the meteorites are still contaminated.

Queenie Hoi Shan Chan, planetary scientist at Royal Holloway, University of London

Sample-return missions can deliver clean space rocks to Earth



ASTRONOMY

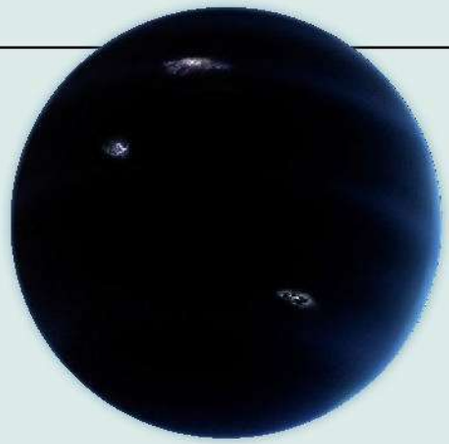
What can we hope to see from future big telescopes?

They're a big step forwards from what we have now, where the best telescope in the world is the Very Large Telescope (VLT) in Chile. It will be a big change when we have these larger ones. There are two being planned in America, plus the unimaginatively named Extremely Large Telescope (ELT), which plans to have a 39-metre (127-foot) mirror. That will have the capability to see very, very faint objects, and I'll be interested in looking as far back in time as we can and therefore as far away as we can. Also, I'll be very interested in what it can do for planets around other stars. In order to take images of planets around another star, you've got the problem of looking at a firefly very near to a searchlight, as it were, only much fainter. The ELT will have the combination of collecting power and angular resolution. It will enable astronomers using a high-level spectrograph to distinguish between the light of the star and the much smaller contribution coming from the reflected light of the planet, thereby learning something about the planet – whether it's got lots of clouds, topographical features, the length of the day and so on.

Martin Rees, British Astronomer Royal, best known for his work on some of the most exotic and extreme objects in the cosmos

"Planet Nine makes us look much more like the rest of the galaxy"

Mike Brown



SOLAR SYSTEM

What does existing evidence of Planet Nine tell us about the Solar System?

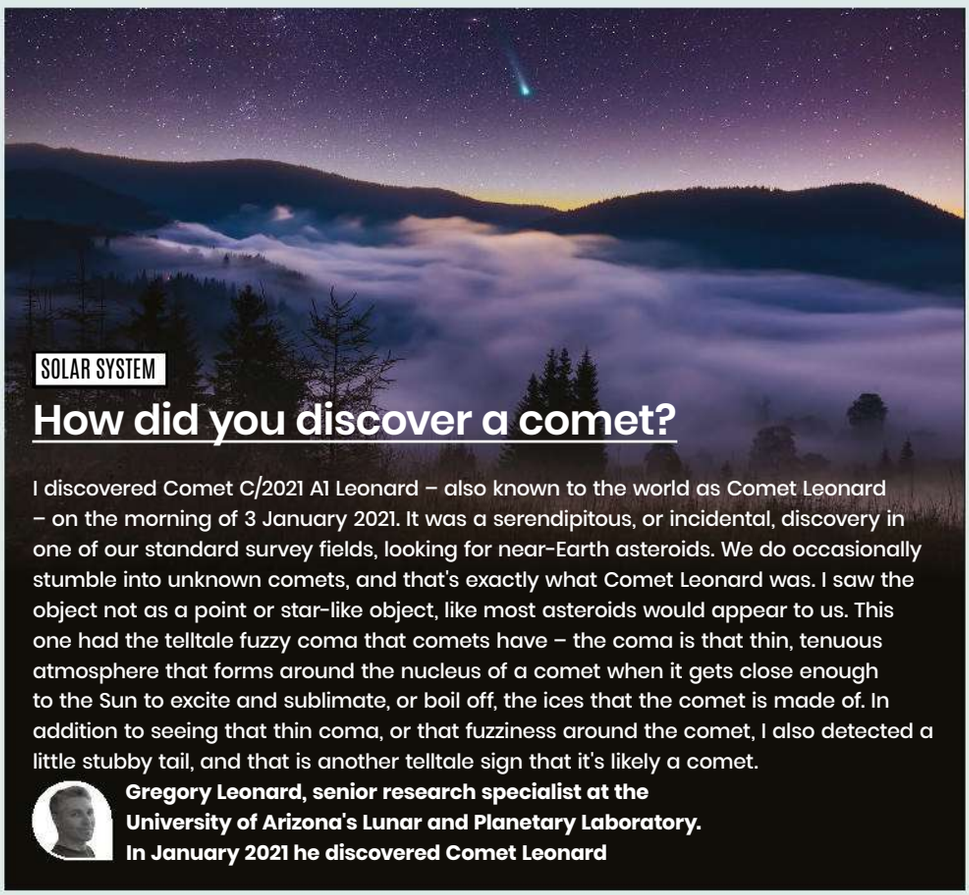
The Solar System has always seemed to be an oddball, and we haven't found anything quite like it. What's interesting is that we always say the most common type of planet in the entire galaxy is one somewhere between the mass of Earth and the mass of Neptune, but isn't it strange that we don't have anything like that in the Solar System? Now it looks like we do. Another thing is that most planets in the galaxy are on eccentric orbits, and all of our planets are on these circular orbits. Suddenly, Planet Nine makes us look much more like the rest of the galaxy. One of the big implications, for me, is that by finding this very strange planet on the outer edge of our Solar System, the Solar System becomes much more normal than it was before.

Dr Mike Brown, professor of planetary astronomy at the California Institute of Technology

A Planet Nine could lurk beyond Pluto

B Telescope technology is always advancing

C Comet Leonard had a close encounter with Venus



SOLAR SYSTEM

How did you discover a comet?

I discovered Comet C/2021 A1 Leonard – also known to the world as Comet Leonard – on the morning of 3 January 2021. It was a serendipitous, or incidental, discovery in one of our standard survey fields, looking for near-Earth asteroids. We do occasionally stumble into unknown comets, and that's exactly what Comet Leonard was. I saw the object not as a point or star-like object, like most asteroids would appear to us. This one had the telltale fuzzy coma that comets have – the coma is that thin, tenuous atmosphere that forms around the nucleus of a comet when it gets close enough to the Sun to excite and sublimate, or boil off, the ices that the comet is made of. In addition to seeing that thin coma, or that fuzziness around the comet, I also detected a little stubby tail, and that is another telltale sign that it's likely a comet.

Gregory Leonard, senior research specialist at the University of Arizona's Lunar and Planetary Laboratory. In January 2021 he discovered Comet Leonard

© Getty Images; NASA/Caltech/R. Hurt (IPAC)

SPACE EXPLORATION

What's the most dangerous incident that has ever happened in space?

When you venture on a spacewalk, you know that you're doing the highest risk element of any mission in space, but probably the last thing you'd expect to happen is to drown. This actually nearly happened to my Italian classmate Luca Parmitano back in 2013. He was on his first spacewalk and he felt water coming into his helmet.

Mission Control thought it must be coming from his drink bag, so they said "Luca, just drink it; the bag must be leaking," which he did. The water feels very cold, and the drink bag's now empty and there is still water coming in. They realised they had to get Luca back in a hurry, and by the time Luca got back to the airlock, the water had come completely over the top of his head. It cut out all of his communication systems, so he couldn't hear. He couldn't talk. He couldn't see because the water was in his eyes and coming over the top of his nose and mouth. It was the closest we've come to losing a crew member on the space station.

When we were out in space for about four hours, Tim Kopra pulled up and said: "I've got water coming into my helmet." In fact, he was using the same spacesuit that Luca had used a few years prior, so we knew it was a dangerous situation. We had to get Kopra back into the airlock in a hurry and terminate the spacewalk. But, interestingly, NASA had introduced two changes to the spacesuit since Luca's incident. One was to have a breathing tube that went from the helmet down to the torso, so at least you could put your mouth over this breathing tube and breathe from a different part of the spacesuit. And the second was to have a nappy in the back of that particular helmet to absorb any water that could come again. A snorkel and a nappy – it doesn't always take a high-tech solution for solving a complex problem.

Major Tim Peake, the European Space Agency's (ESA) first British astronaut after launching into space on board a Soyuz rocket in December 2015

"He was on his first spacewalk and he felt water coming into his helmet"

Tim Peake

FOCUS ON

WORMHOLES MIGHT BEND LIGHT LIKE BLACK HOLES DO

If these portals exist, they might magnify distant objects according to Einstein's theory of relativity

Reported by JoAnna Wendel

If wormholes exist, they could magnify the light of distant objects by up to 100,000 times, and that could be the key to finding them. Wormholes are theoretical funnel-shaped portals through which matter – or perhaps spacecraft – could travel great distances. To imagine a wormhole, suppose all of the universe were a sheet of paper. If your starting point were a dot at the top of the sheet and your destination were a dot on the bottom of the sheet, the wormhole would appear if you folded that sheet of paper so that the two dots met. You could traverse the entire sheet in an instant, rather than travelling the entire length of the sheet.

Wormholes have never been proven to exist, but physicists have nonetheless spent decades theorising what these exotic objects might look like and how they might behave. In a new study, researchers built a model to simulate an electrically charged spherical wormhole and its effects on the universe around it. The researchers wanted to find out whether wormholes could be detectable by their observed effects on their surroundings.

The researchers' model shows that wormholes, should they exist, could be massive enough to trigger one aspect of Einstein's theory of general relativity: that extremely massive objects bend the fabric of space-time to such a degree that they cause light to curve. This bent light magnifies whatever lurks behind the massive object as seen from our perspective on Earth. This phenomenon is known as 'microlensing', and it allows scientists to use massive objects, like galaxies and black holes, to view extremely distant objects, like stars and galaxies from the early universe.

In their study, the researchers argue that wormholes, much like black holes, would be massive enough to magnify distant objects behind them. "The magnification via the distortion by a wormhole can be very large, which could be tested one day," lead scientist Lei-Hua Liu, a physicist at Jishou University in Hunan, China, said. Liu also noted that wormholes would magnify objects differently than black holes do, meaning scientists could distinguish the two. For example, microlensing via a black hole is known to produce four mirror images of the object behind it. Microlensing via a wormhole, on the other hand, would produce three images – two dim ones and one very bright one, simulations showed.

However, because other objects – like galaxies, black holes and stars – also produce a microlensing effect, finding a wormhole with no clear clues about where to start looking would be a difficult undertaking, said Andreas Karch, a physicist at the University of Texas at Austin who was not involved in the study. Trying to tease out the microlensing caused by a wormhole versus other large objects would be like "trying to make out the soft voice of a single person in the middle of a rock concert," Karch said. He also noted that while the researchers offered an interesting theoretical way to identify wormholes, "they don't even talk about how to do this in practice yet – that's future work." Although wormholes are still solidly theoretical, the fact that the new model could one day be tested is "the dream for most physicists," Liu added.

HOW WORMHOLES ARE MADE

If these space-time tunnels do exist, what would they look like and how would they come into existence?

1 Collapse of the core

When a gigantic star dies, sometimes a black hole is formed. The core collapses in on itself in the catastrophic explosion of a supernova. The devastated star's outer layers are expelled into space, while the core continues to shrink in size.

2 A cosmic plughole

Shrinking over thousands of years, the core collapses into an even smaller size. While it has shrunk to a speck, all of its mass is now concentrated in a very small area, known as a singularity. It might be small, but it's so heavy that it has the ability to bend space-time. Not even light can escape the gravitational pull of the singularity.

3 The makings of a doughnut

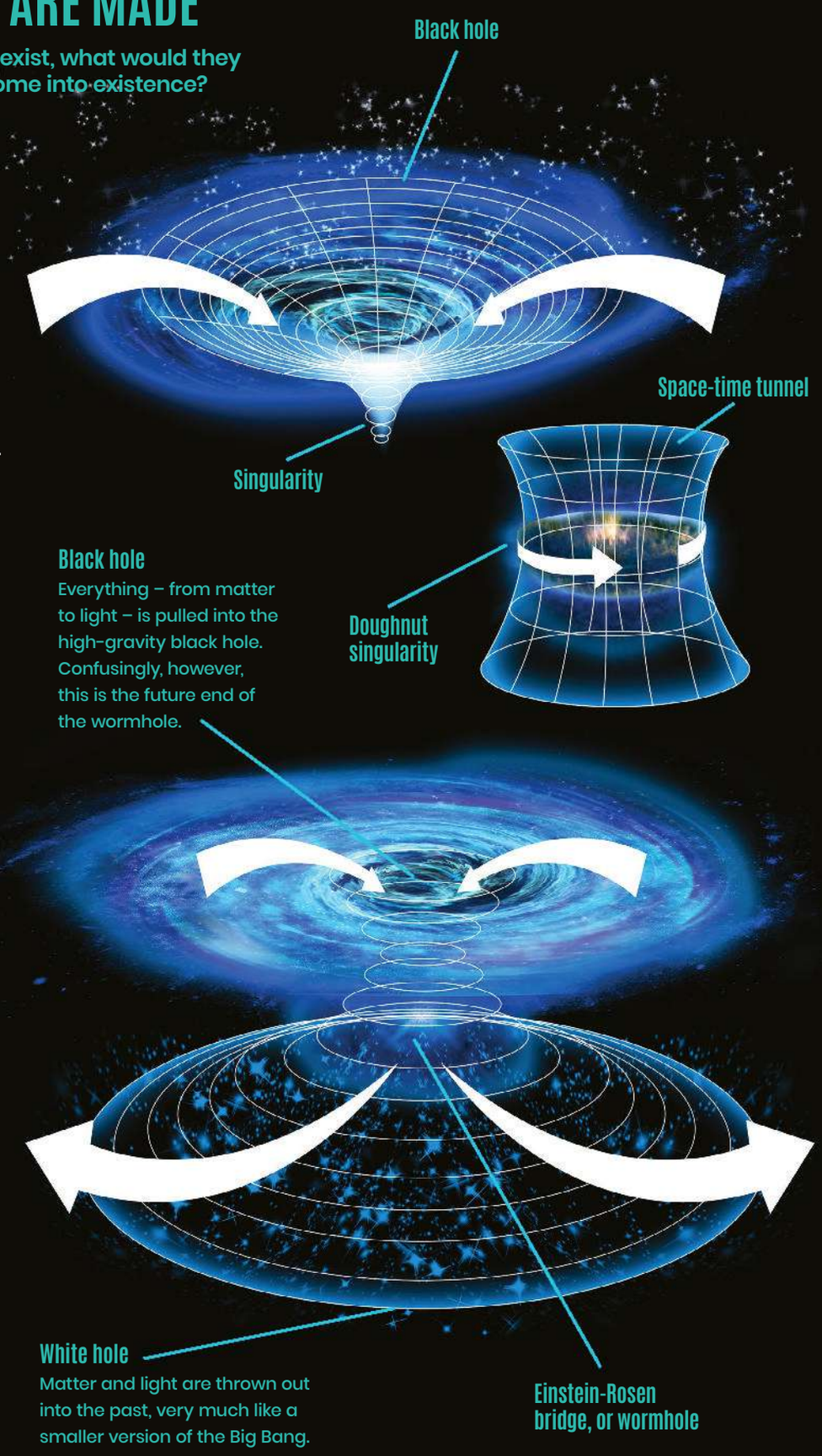
A star's core can still be found to be spinning when it decides to collapse. Crumbling to a singularity, it begins to rotate faster and faster. It spins so quickly that what's left of the star's material spreads out and is moulded into a doughnut. Space-time is no longer focused on a single point; it's now being wrapped around this space ring, creating a tunnel.

4 Punching through space

The tunnel being made punches its way through the fabric of space-time and, almost in a state of reversal, it emerges backwards in time and into the past. Matter grabbed by the black hole is passed through this tunnel.

5 Meet the white hole

If you were to travel through a wormhole, you would reach its far side, which can be likened to a black hole in reverse: the white hole. Matter pulled in by the black hole will emerge from the singularity found at the white hole's centre and be released back into space.


Black hole
Space-time tunnel
Singularity
Black hole
Everything – from matter to light – is pulled into the high-gravity black hole. Confusingly, however, this is the future end of the wormhole.
Doughnut singularity
White hole
Matter and light are thrown out into the past, very much like a smaller version of the Big Bang.
Einstein-Rosen bridge, or wormhole

© Getty

WHAT'S IN THE SKY?

What to look out for during this observing period

In this issue...

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20 APRIL
Dwarf planet Haumea reaches opposition

20 APRIL
Hybrid solar eclipse visible from western Australia, East Timor and eastern Indonesia

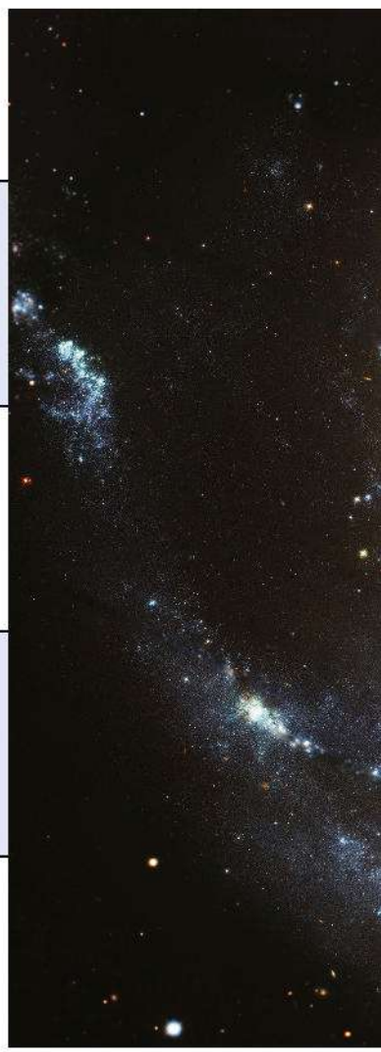
23 APRIL
The Lyrid meteor shower reaches its peak

23 APRIL
The Moon and Venus make a close approach, passing within 1°17' of each other in Taurus

23 APRIL
Conjunction between the Moon and Venus in Taurus

24 APRIL
The Pinwheel Galaxy (Messier 101) is well placed for observation in Ursa Major

26 APRIL
Conjunction between the Moon and Mars in Gemini



"Comet 237P/LINEAR will make its closest approach to the Sun, scheduled to reach +10.8"

26 APRIL
The Moon and Venus make a close approach, passing within 3°13' of each other in Gemini

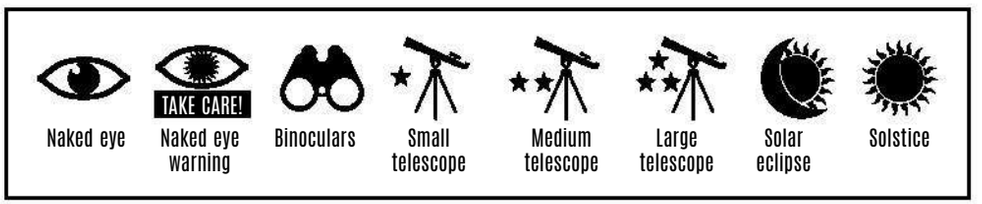
28 APRIL
Venus reaches its highest point in the evening sky, dazzling at magnitude -4.3

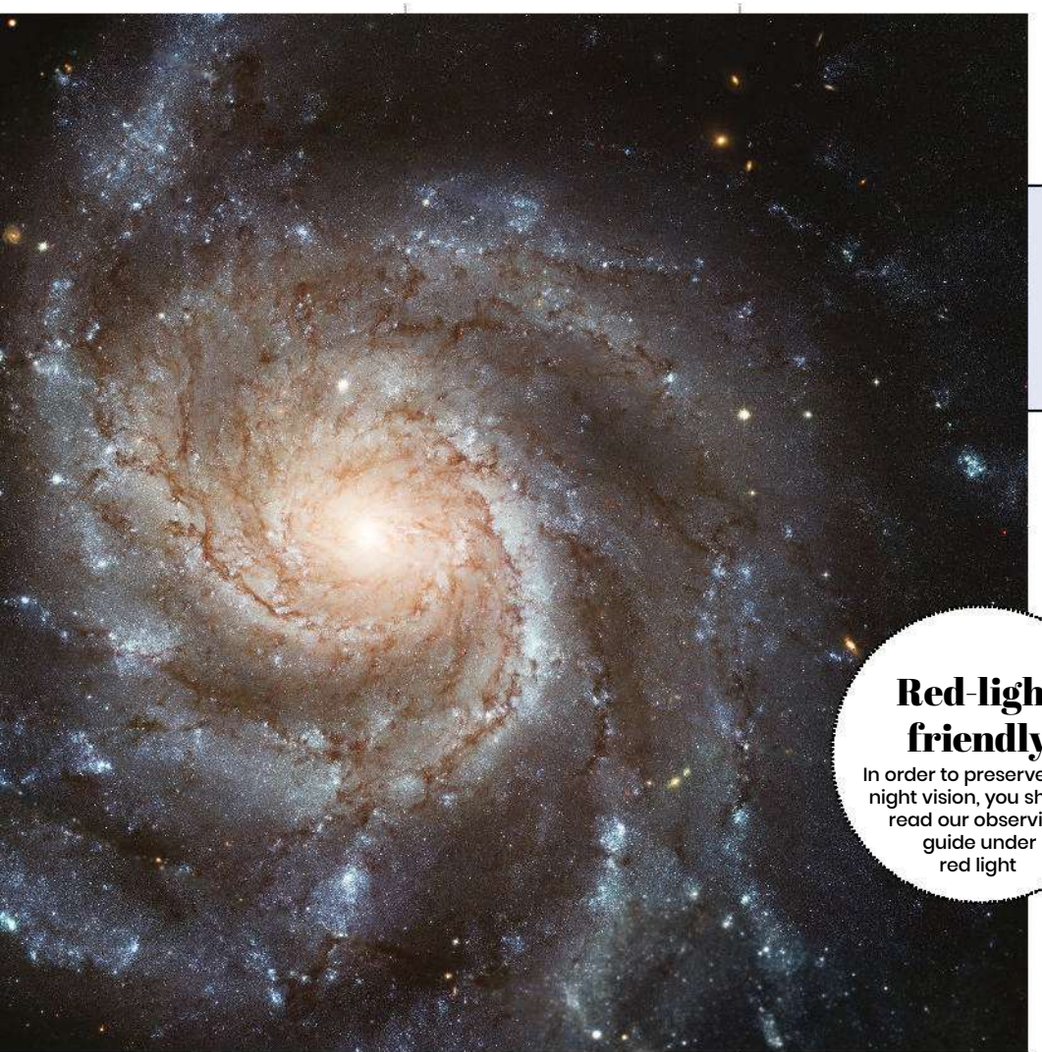
30 APRIL
Asteroid 7 Iris reaches opposition in Libra

9 MAY
The Eta Lyrid meteor shower reaches its peak

13 MAY
Globular cluster Messier 5 is well placed for observation in Serpens

13 MAY
Conjunction between the Moon and Saturn in Aquarius





Red-light friendly

In order to preserve your night vision, you should read our observing guide under red light

5 MAY

A penumbral eclipse will be visible from any location where the Moon is above the horizon

6 MAY

The Eta Aquariid meteor shower reaches its peak

7 MAY

The Moon passes in front of Delta Scorpii, creating a lunar occultation

13 MAY

The Moon and Saturn make a close approach, passing within 2°59' of each other in Aquarius

14 MAY

Comet 237P/LINEAR will make its closest approach to the Sun, scheduled to reach +10.8

17 MAY

The Moon will pass in front of Jupiter, creating a lunar occultation

Jargon buster

Conjunction

An alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

Declination (Dec)

How high an object will rise in the sky. Like Earth's latitude, Dec measures north and south in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and 60 arcminutes in a degree.

Opposition

When a celestial body is in line with Earth and the Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

Right Ascension (RA)

RA is to the sky what longitude is to Earth, corresponding to east and west. It's measured in hours, minutes and seconds, as since Earth rotates on its axis, we see different parts of the sky throughout the night.

Magnitude

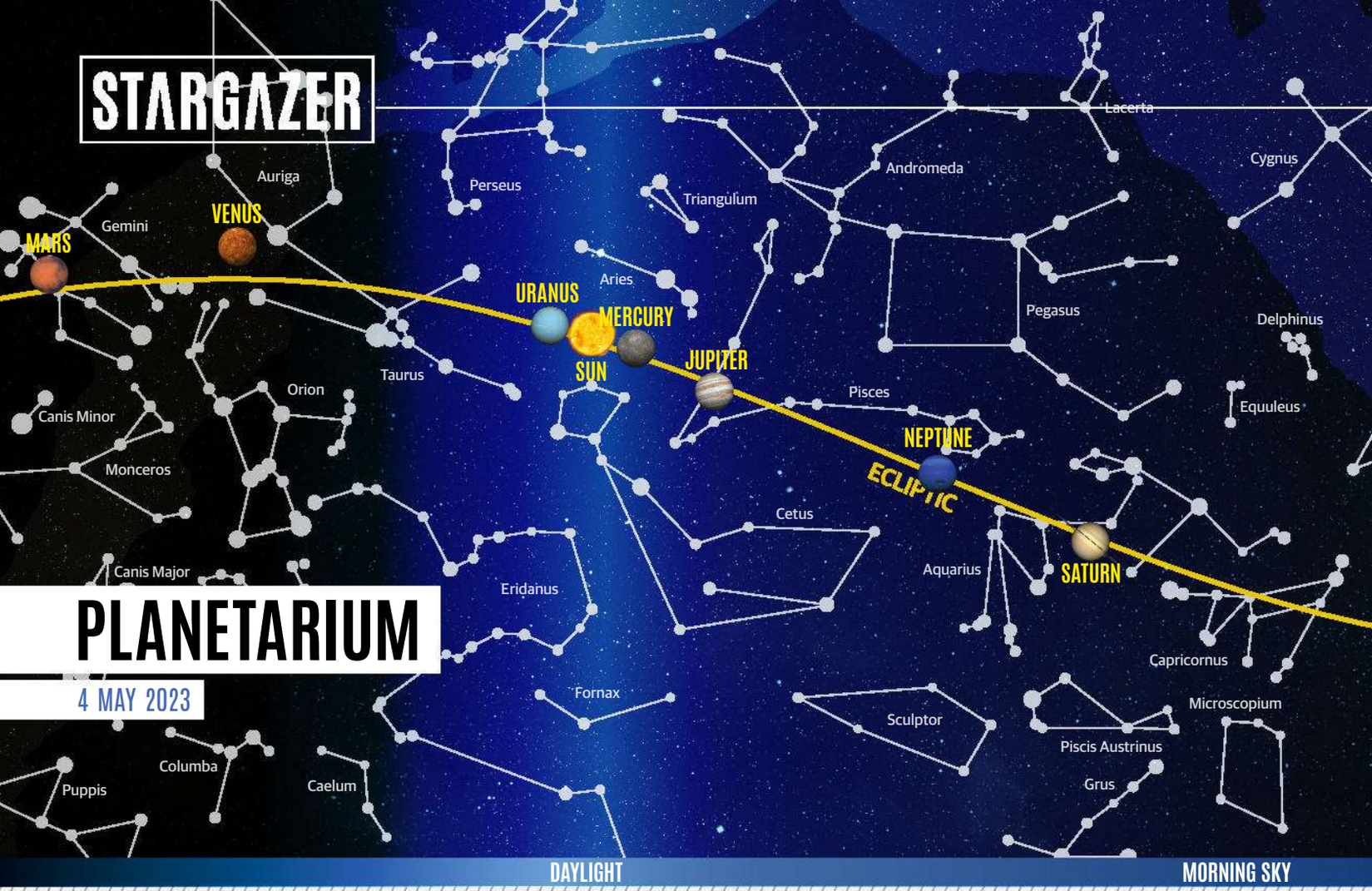
An object's magnitude tells you how bright it appears from Earth, represented on a numbered scale. The lower the number, the brighter the object. A magnitude of –1.0 is brighter than +2.0.

Greatest elongation

When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongation and as morning stars during western elongation.

© ESA; NASA

STARGAZER



PLANETARIUM

4 MAY 2023

DAYLIGHT MORNING SKY

MOON CALENDAR

* The Moon does not pass the meridian on 4 May

20 APR	21 APR	22 APR	23 APR
NM			
0.1%	2.3%	6.7%	13.1%
06:04 20:47	06:20 22:10	06:40 23:31	07:06 --:--

24 APR	25 APR	26 APR	27 APR	28 APR	29 APR	30 APR
			FQ			
20.9%	29.7%	39.2%	48.9%	58.7%	68.1%	76.9%
00:46 07:42	01:49 08:30	02:38 09:30	03:14 10:37	03:39 11:49	03:59 13:02	04:13 14:15

1 MAY	2 MAY	3 MAY	4 MAY	5 MAY	6 MAY	7 MAY
				FM		
84.8%	91.4%	96.4%	--.--*	99.3%	99.9%	97.9%
04;26 15:27	04:37 16:40	04:48 17:55	05:00 19:13	05:13 20:35	05:31 22:01	05:55 23:26

8 MAY	9 MAY	10 MAY	11 MAY	12 MAY	13 MAY	14 MAY
				TQ		
93.2%	86.0%	76.7%	65.9%	54.2%	42.2%	30.9%
06:31 --:--	00:42 07:22	01:42 08:32	02:25 09:56	02:55 11:24	03:16 12:52	03:32 14:18

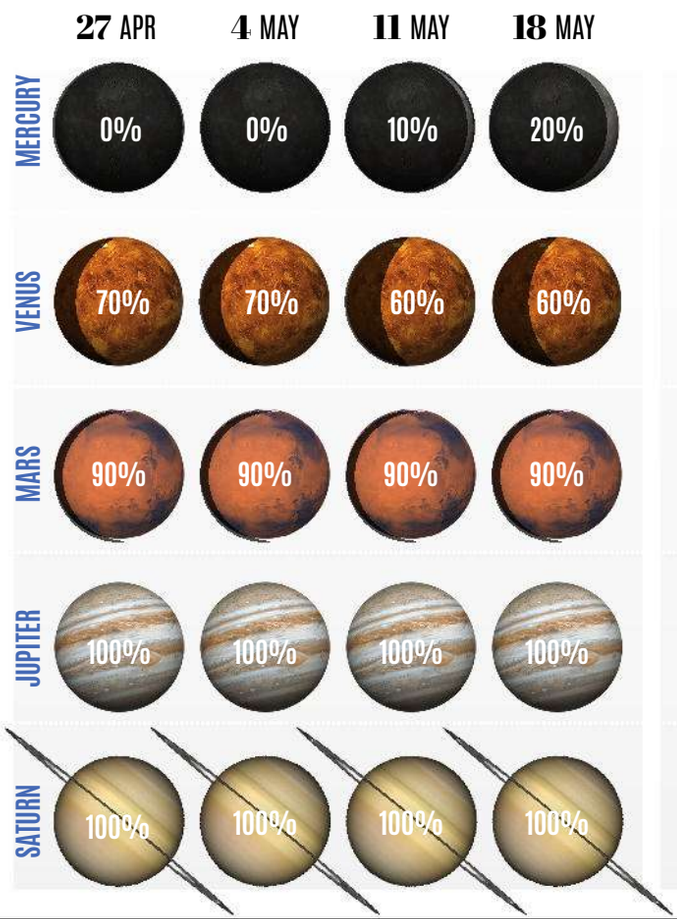
15 MAY	16 MAY	17 MAY	18 MAY
20.7%	12.1%	5.7%	1.7%
03:45 15:41	03:58 17:03	04:11 18:25	04:25 19:47

% Illumination
Moonrise time
Moonset time

FM Full Moon
NM New Moon
FQ First quarter
TQ Third quarter

All figures are given for 00h at midnight (local times for London, UK)

ILLUMINATION PERCENTAGE



PLANET POSITIONS

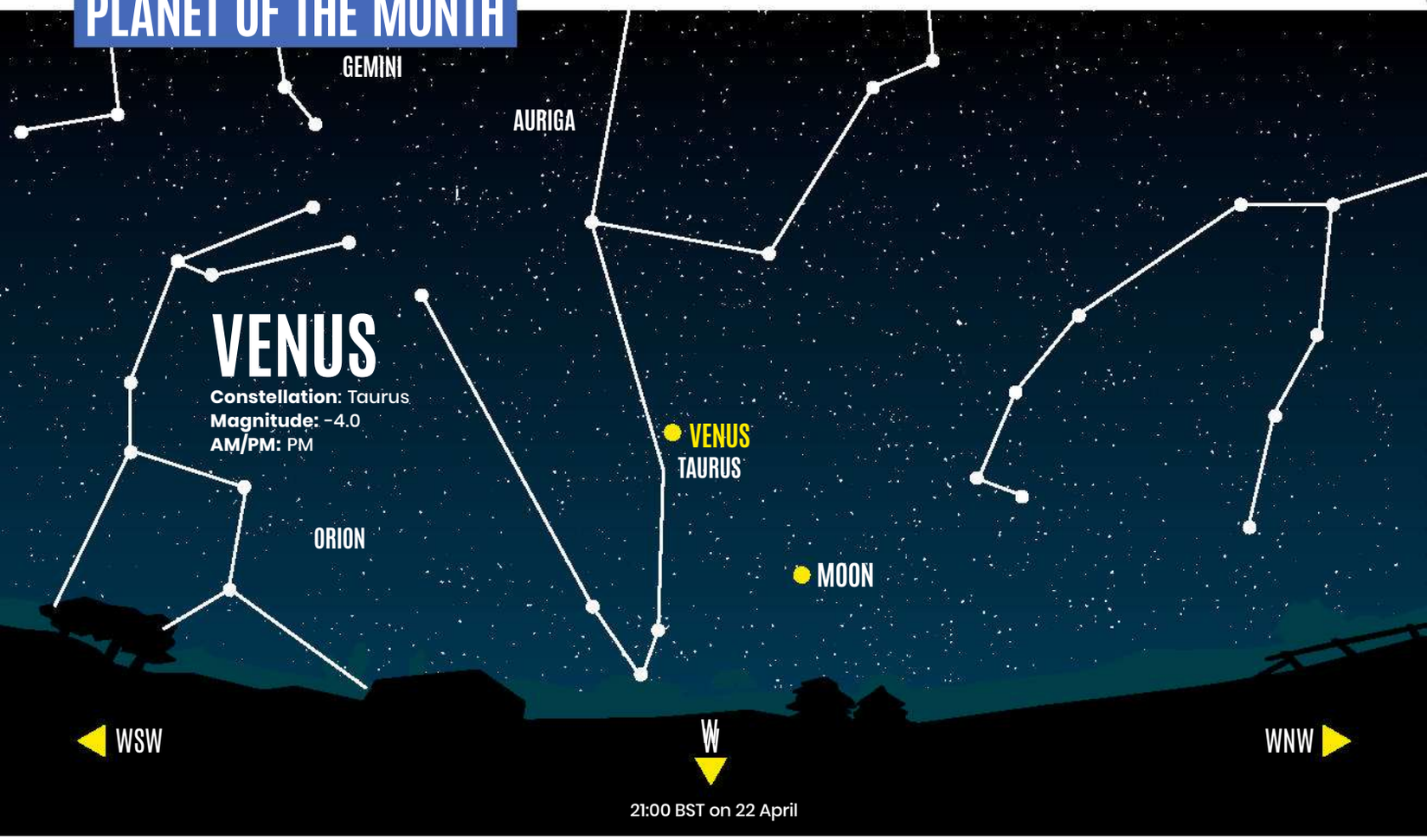
All rise and set times are given in BST

DATE	RA	DEC	CONSTELLATION	MAG	RISE	SET
20 APR	02h 47m 21s	+19° 11' 13"	Aries	+1.7	06:06	21:44
27 APR	02h 43m 16s	+17° 52' 12"	Aries	+4.4	05:43	21:05
4 MAY	02h 29m 02s	+14° 50' 09"	Aries	+6.0	05:19	20:05
11 MAY	02h 17m 50s	+11° 53' 18"	Aries	+3.1	04:57	19:09
18 MAY	02h 18m 17s	+10° 33' 30"	Aries	+1.6	04:38	18:35
20 APR	04h 31m 36s	+23° 52' 03"	Taurus	-4.1	07:18	00:00
27 APR	05h 06m 15s	+25° 08' 22"	Taurus	-4.1	07:15	00:17
4 MAY	05h 40m 53s	+25° 52' 54"	Taurus	-4.1	07:16	00:30
11 MAY	06h 15m 05s	+26° 05' 12"	Gemini	-4.1	07:21	00:38
18 MAY	06h 48m 27s	+25° 46' 00"	Gemini	-4.1	07:29	00:42
20 APR	06h 56m 02s	+24° 41' 35"	Gemini	+1.2	09:35	02:31
27 APR	07h 12m 28s	+24° 12' 31"	Gemini	+1.3	09:28	02:16
4 MAY	07h 29m 04s	+23° 36' 50"	Gemini	+1.4	09:21	02:01
11 MAY	07h 45m 45s	+22° 54' 32"	Gemini	+1.4	09:16	01:45
18 MAY	08h 02m 28s	+22° 05' 39"	Cancer	+1.5	09:11	01:28
20 APR	01h 28m 07s	+08° 05' 37"	Pisces	-2.0	05:51	19:22
27 APR	01h 34m 26s	+08° 42' 32"	Pisces	-2.0	05:26	19:04
4 MAY	01h 40m 42s	+09° 18' 33"	Pisces	-2.0	05:02	18:45
11 MAY	01h 46m 55s	+09° 53' 32"	Pisces	-2.1	04:37	18:27
18 MAY	01h 53m 03s	+10° 27' 22"	Pisces	-2.1	04:13	18:09
20 APR	22h 26m 24s	-11° 15' 00"	Aquarius	+1.0	04:30	14:40
27 APR	22h 28m 36s	-11° 03' 36"	Aquarius	+1.0	04:03	14:16
4 MAY	22h 30m 34s	-10° 53' 33"	Aquarius	+1.0	03:37	13:51
11 MAY	22h 32m 18s	-10° 44' 56"	Aquarius	+1.0	03:10	13:26
18 MAY	22h 33m 46s	-10° 37' 52"	Aquarius	+1.0	02:43	13:01

THIS MONTH'S PLANETS

As we move into late spring, Venus remains a dazzling target

PLANET OF THE MONTH



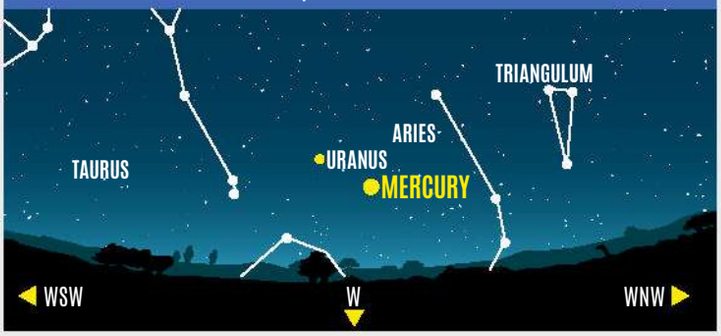
Venus is the brightest planet on view this month. There are some interesting things going on around it, but the other planets are all much more poorly placed and harder to see. Venus is known by many people as the 'evening star', but it can also shine before dawn. It's often called 'Earth's twin', but that's a very inaccurate label: it is a hellish planet with crushing atmospheric pressures, lethal surface temperatures and a sky so thick with curdled carbon dioxide clouds that its rocky, fractured surface is never bathed in sunlight. It's ironic that it's named after the goddess of love because it shines so beautifully in our sky.

At the start of our observing period Venus will be a beautiful 'evening star', visible as a silvery spark in the twilight soon after sunset and strikingly bright by the time darkness has fallen properly. Embedded in the glittering stars of Taurus, forming the peak of a triangle with the famous Hyades and Pleiades star clusters, Venus will shine brighter than anything else in the sky apart from the Sun and Moon, and by 22:00 on the cool nights of late April it will be quite a lovely sight to the naked eye and through binoculars and telescopes. Mars, shining to its upper left, will be an underwhelming, pale-orange star in comparison.

Late April will also see Venus having a close encounter with the Moon. Look to the northwest as twilight deepens on the evening of 22 April and you'll see a beautiful crescent Moon shining to the lower right of Venus, between it and the Pleiades star cluster. The following evening, on the 23rd, the Moon will be shining to Venus' upper left. On both of these evenings the unlit part of the Moon's face should be glowing with lavender-hued 'earthshine', which will be visible to the naked eye but much more conspicuous through a pair of binoculars.

As April ends and May begins, Venus will pull away from the two star clusters, heading towards Mars. But it will still set four hours after the Sun, will still be in Taurus' region of the sky and will still dominate the spring sky. By 18 May, after being trapped inside its invisible borders for many months, Venus will finally break free from Taurus and move into neighbouring Gemini. By then it will be just 17 degrees away from Mars, and the two planets' contrasting colours will be obvious to the naked eye, and even more so in binoculars.

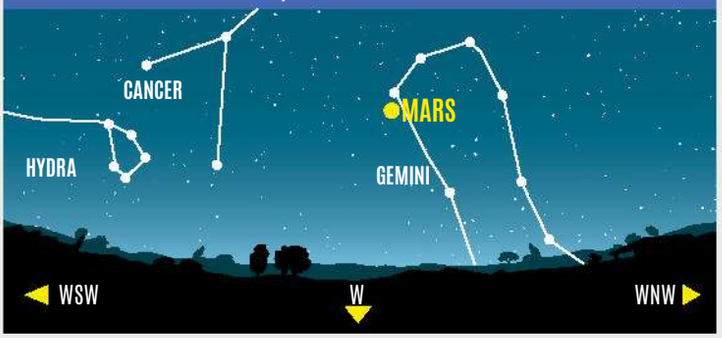
MERCURY 18:00 BST on 26 April



Constellation: Aries **Magnitude:** +1.9 **AM/PM:** PM

At the start of our observing period Mercury is an unimpressive, coppery-hued evening star, shining very low in the west after sunset to the lower right of much brighter Venus and setting around an hour and a half after the Sun. But it will already be at its best for the month. As the evenings pass, it will set a little earlier every night.

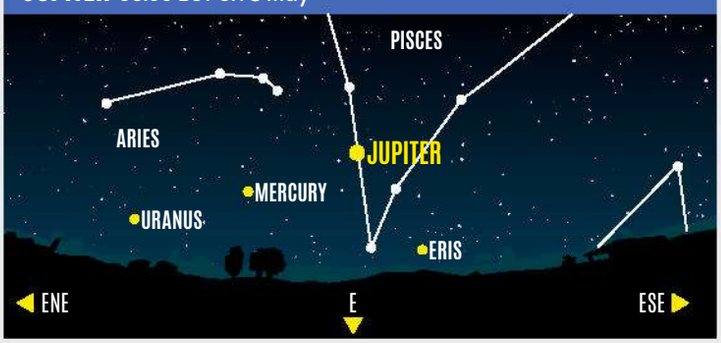
MARS 21:45 BST on 8 May



Constellation: Gemini **Magnitude:** +1.2 **AM/PM:** PM

By mid-April Mars will be an orange evening star, visible in the west as soon as the sky begins to grow dark after sunset and visible all through the evening, setting in the early hours of the following morning. With a magnitude of +1.2 it will be as bright as Pollux, which it will slowly be moving towards as it pushes up into Gemini.

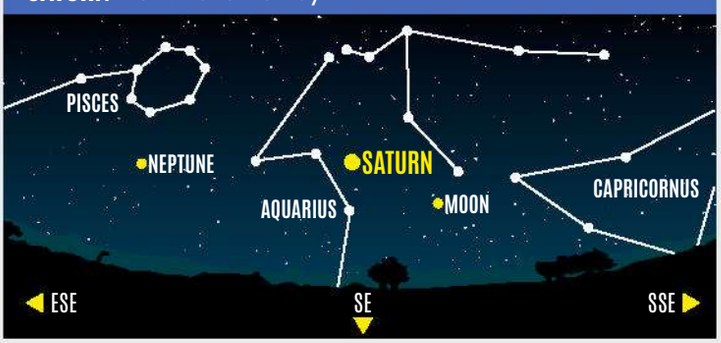
JUPITER 06:00 BST on 8 May



Constellation: Pisces **Magnitude:** -2.0 **AM/PM:** AM

At the start of our observing period, Jupiter, by far the largest world in our Solar System, will technically be a morning object, but it will be too close to the Sun to be visible. As the days pass, this giant gas world will pull away from the Sun, but will remain too close to our star to be visible for a while.

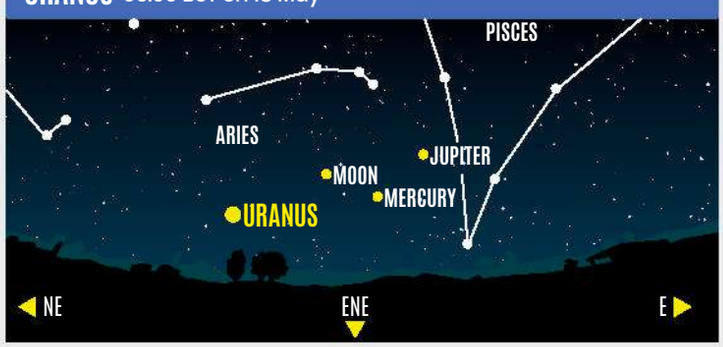
SATURN 06:00 BST on 13 May



Constellation: Aquarius **Magnitude:** +1.0 **AM/PM:** AM

You'll have to get up early this month if you want to see Saturn because it will be a morning star, visible only briefly before the Sun comes up. At the start of our observing period the Ringed Planet will be rising less than an hour before sunrise, and by the middle of May it will be rising an hour and a half before the Sun.

URANUS 05:00 BST on 18 May



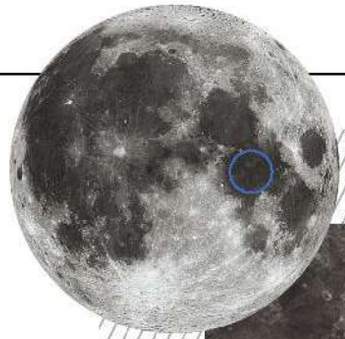
Constellation: Aries **Magnitude:** +5.8 **AM/PM:** PM

At the start of our observing period the ice giant Uranus will be an evening object, very low in the west after sunset, shining to the left of brighter Mercury and to the lower right of much brighter Venus, setting an hour and a half after the Sun. By 18 May Uranus will have moved into the morning sky, rising only 15 minutes before the Sun.

NEPTUNE 06:00 BST on 18 May

Constellation: Pisces **Magnitude:** +7.9 **AM/PM:** AM

This month Neptune will be a morning object, visible only in the morning twilight and making it very hard to see at all. As April draws to a close it will be rising in the east only half an hour before the Sun, and by the time mid-May comes around it will be rising only half an hour earlier than that.



MOON TOUR

THE SEA OF TRANQUILLITY

Find the Eagle's landing site in the most famous sea on the Moon

It seems almost impossible to believe it was so long ago, but as this summer rolls around, it will be 54 years since the first humans walked on the Moon. Over half a century ago in July 1969, with the world watching and with their crewmate Michael Collins orbiting the Moon high above them, Neil Armstrong and Buzz Aldrin skilfully guided the Apollo 11 Lunar Module, Eagle, down to the surface of the Moon.

After a tense few last moments of flying low over a boulder field in search of a safe landing site, they finally set their spindly looking spacecraft down near the southern 'shore' of one of the Moon's mare, or seas, which are not seas like those we have here on Earth, but are vast plains of cold, ancient, frozen lava. This sea is now the most famous feature on the Moon – the Sea of Tranquillity.

Named and drawn by early lunar cartographers Francesco Grimaldi and Giovanni Riccioli on their first Moon maps in 1651, the Sea of Tranquillity is a smooth, dark plain more than 870 kilometres (451 miles) across. Ringed with mountains and hills, peppered with many craters and etched with claw mark-like valleys and rilles, the roughly oval-shaped Mare Tranquillitatis lies on the right side of the Moon's Earth-facing side, to the south of the larger and rounder Sea of Serenity and to the north of the smaller seas of Mare Nectaris and Mare Fecunditatis. In contrast to those seas around it, which appear dark and black-grey when photographed, high-resolution images of Mare Tranquillitatis show it has a strong blue tint, which we now know is the result of its basaltic lava having a higher metal content than that of its neighbours.

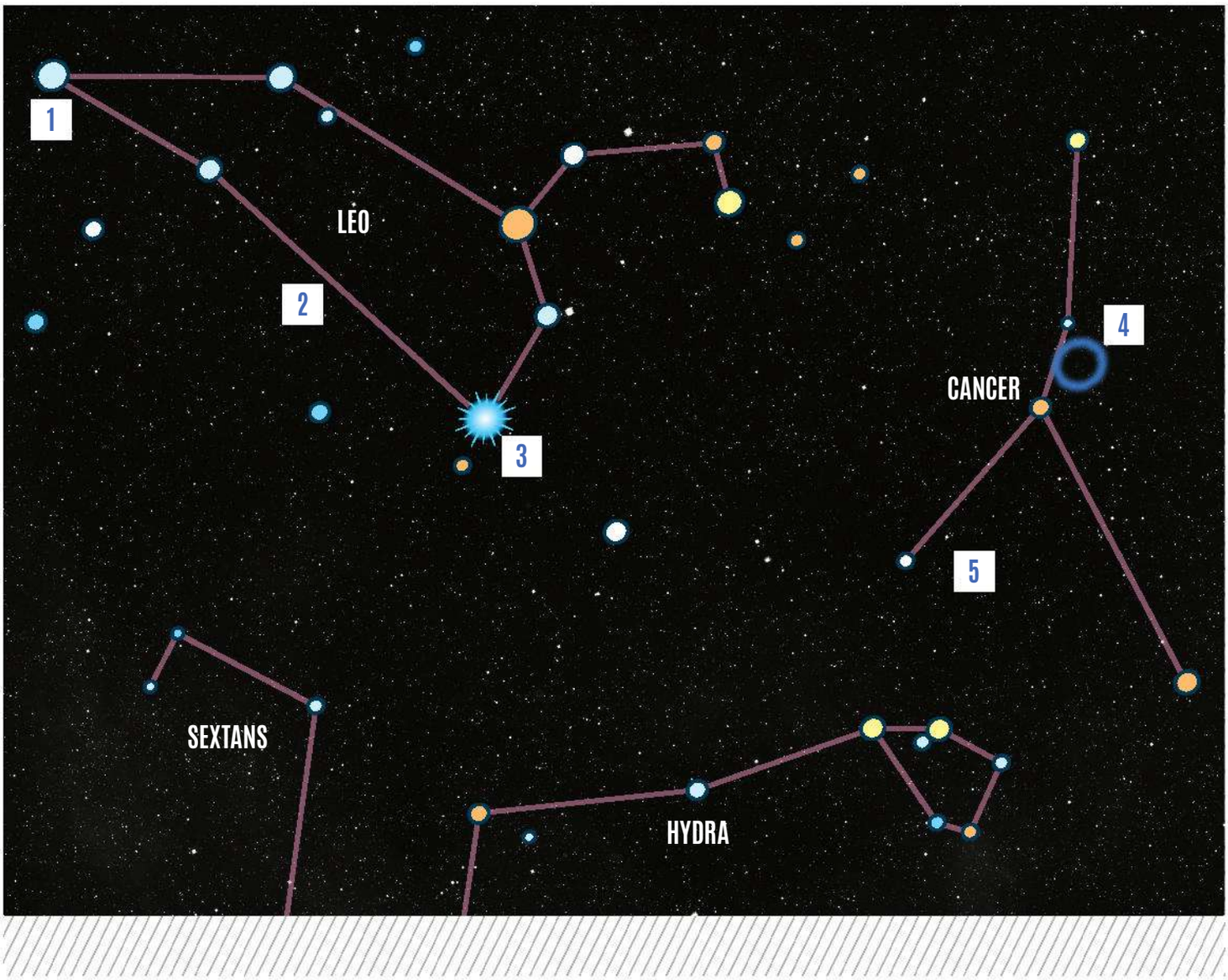
Apollo 11's Eagle Lunar Module wasn't the first spacecraft to reach this silent, still sea. In February 1965 the Ranger 8 probe crashed into it and was destroyed, but not before sending back over 7,000 priceless images of the Moon in the last 23 minutes of its mission. In September 1967, more than a year before the crew of Apollo 8 became the first humans to reach the Moon, the Surveyor 5 probe set down on the Sea of Tranquillity, just 25 kilometres (16 miles) away from the area where the Eagle would land less than two years later.

Luckily, finding the Sea of Tranquillity isn't hard at all. Just look at the Moon on any night between first quarter phase and just after full Moon and you'll be able to spot it as a dark patch in the centre-right area of the Moon's mottled face. At the start of our observing period the Moon will be waning, and Mare Tranquillitatis won't be visible, as it's plunged into darkness. The lunar sea won't reappear until around 25 April, when the Moon is a waxing crescent again. On 28 April, the Sea of Tranquillity – and the Apollo 11 landing site – will be fully illuminated and visible all night. You won't see footprints through your binoculars or telescope, and you certainly won't see the 'Stars and Stripes' flag that blew over as Eagle lifted off the Moon, but you will see the historic area of the Moon where history was made over half a century ago. If you have a telescope, you'll be able to zoom in on the landing area and imagine you were standing inside Eagle behind Neil Armstrong and Buzz Aldrin as they guided their fragile spacecraft down to Tranquillity Base, where, watched by millions staring at flickering black-and-white TV screens all around the world, Armstrong would take his "one small step for man, one giant leap for mankind".

TOP TIP!

Don't expect to see Apollo 11's flag and footprints through your telescope. Not even the Hubble Space Telescope can see those!

© Gregory H. Revera



NAKED EYE AND BINOCULAR TARGETS

The spring sky offers plenty for those without a telescope to hand

1 Denebola (Beta Leonis)

Second-magnitude Denebola is 36 light years away and shines a bright white. Like Regulus, its rapid rotation flattens its poles. It's a young star, perhaps just 400 million years old, and is surrounded by a disc of dust – a solar system in the making.

2 Messier 95

Spiral galaxy

Messier 95 is 32 million light years away from us. At magnitude +9.7, it's so faint you'll need binoculars to see it as a small, round smudge. Long-exposure photographs show its beautiful curved spiral arms and central bar. It's around 70,000 light years across.

3 Regulus (Alpha Leonis)

Shining on the end of the 'Sickle' asterism, magnitude +1.4 Regulus is Leo's brightest star, but only the 21st-brightest star in the sky. Over 70 light years away, it's almost four times larger than our Sun and spins so quickly – once every 16 hours – that it's flattened at its poles.

4 Beehive Cluster (Messier 44)

Also known as Praesepe, Messier 44 is a third-magnitude open cluster. To the naked eye it looks like a full Moon-sized smudge to the right of Leo's Sickle, but binoculars reveal the brightest few dozen of its 1,000 stars.

5 King Cobra Cluster (Messier 67)

Some 12 light years across, this open cluster is an incredible 2,600 light years away. With a low magnitude of +6.9, you'll need your binoculars to find it on a clear, Moon-free night. Estimated to be between 3 and 5 billion years old, this stellar collection is one of the most ancient star clusters known.

5 Bode's Galaxy (Messier 81)

DEEP SKY CHALLENGE

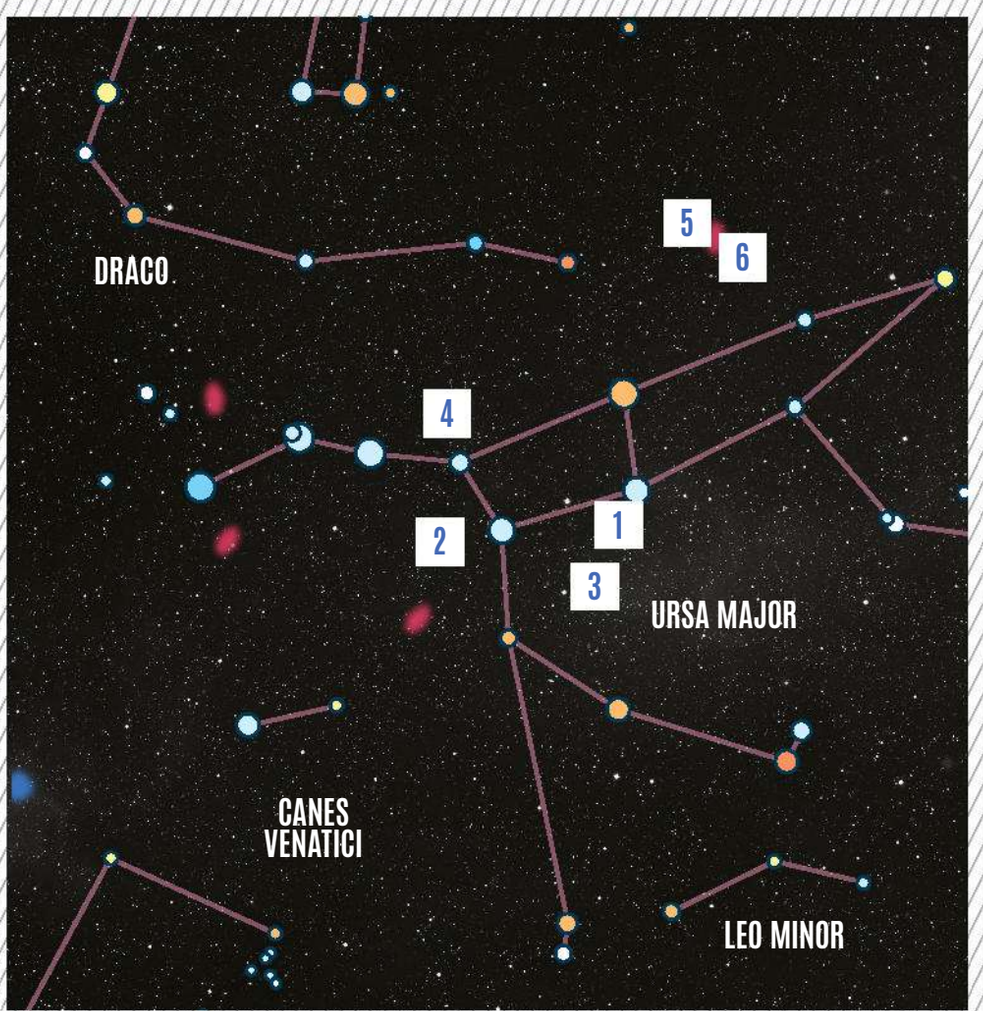
HUNTING FOR FAINT FUZZIES AROUND THE GREAT BEAR

With the Big Dipper hanging overhead, spring nights are perfect for exploring the hidden treasures of Ursa Major

Think of Ursa Major and you probably think of the bright naked-eye stars that make up the Big Dipper. But this northern constellation has a lot more to offer. Lurking inside its boundaries are many deep-sky objects unfamiliar to and unobserved by many telescope owners. There are plenty of galaxies for those who like hunting down those faint, distant star cities, and brighter nebulae within our Milky Way too. The Owl Nebula is very popular with observers of planetary nebulae because it really does resemble the face of a wise old owl when seen through a high-power eyepiece in a large telescope. The close pairing of Messier 81 and 82 is much loved by owners of small telescopes, but only larger instruments will show detail in the arms and centres of these galaxies.

4 Messier's Mistake (Messier 40)

2 Messier 109



1 Messier 108

This barred spiral galaxy is 45 million light years away. Shining at magnitude +10.0, it's visible as a featureless, elongated smudge in six-inch telescopes.

2 Messier 109

Magnitude +9.7 and 82 million light years away, this barred spiral galaxy is a small, pear-shaped blur in small telescopes. Instruments of six inches and above will show the subtle glow of its spiral arms.

3 The Owl Nebula (Messier 97)

Faint and with a low surface brightness, you'll need at least a medium-aperture telescope to see the two dark 'eyes' of this magnitude 9.8 planetary nebula.

4 Messier's Mistake (Messier 40)

This object is an anomaly in Messier's famous catalogue because it's not a galaxy, nebula or cluster, but a close pair of ninth-magnitude stars. It's a 'line-of-sight' double rather than a genuine binary.

5 Bode's Galaxy (Messier 81)

At magnitude +6.8, this spiral galaxy is bright enough to be visible in binoculars as a tiny smudge, but it takes telescopes of six inches and larger to show its spiral arms and bright core.

6 Cigar Galaxy (Messier 82)

Just over half a degree away from Messier 81, Messier 82 – called the Cigar Galaxy due to its elongated appearance – is much smaller and fainter than its more obvious neighbour. A large telescope will reveal light and dark patches along it.

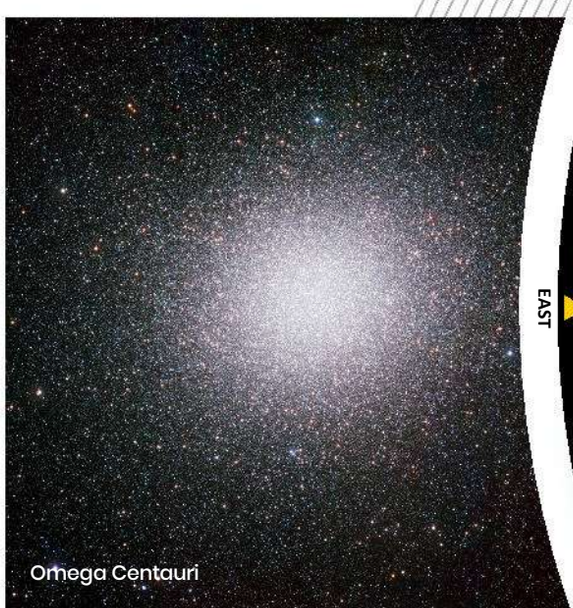
© Wil Tirion; NASA, ESA, SDSS; NOAO; Hewholooks;

NORTHERN HEMISPHERE

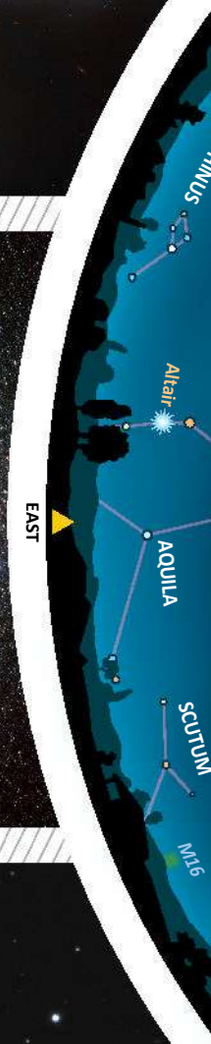
The warmer months have arrived, bringing an impressive array of targets

Summer has almost returned, bringing with it warmer nights. While the cold evenings of winter provide dark skies and longer observing sessions, May still has a lot to offer in the way of vibrant nebulae, star clusters and galaxies. By mid-May at 22:00, Jupiter and Mars are joined by the constellations of Canes Venatici (the Hunting Dogs), Virgo (the Virgin), Coma Berenices (Berenice's Hair) and parts of Centaurus (the Centaur). Globular cluster Omega Centauri glows at magnitude +3.9 and makes its appearance from the east to set in the west. NGC 5128, or the Hamburger Galaxy, contains multiple layers of dust and is one of the brightest galaxies in the sky.

Antennae Galaxies (NGC 4038 and NGC 4039)


Omega Centauri

NGC 4361



Using the sky chart

This chart is for use at 22:00 mid-month and is set for 52 degrees latitude.

1. Hold the chart above your head with the bottom of the page in front of you.
2. Face south and notice that north on the chart is behind you.
3. The constellations on the chart should now match what you see in the sky.

Magnitudes

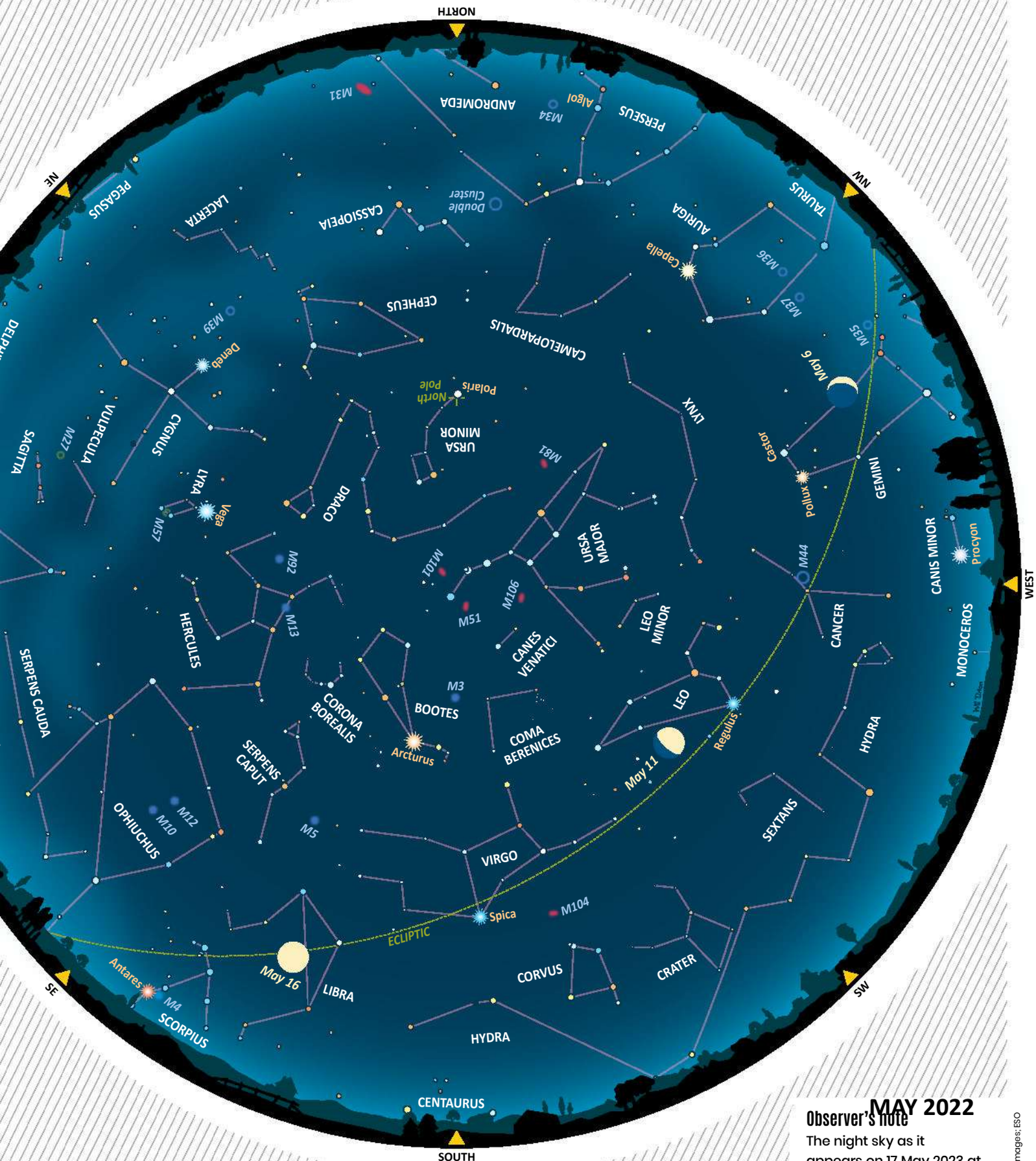
- Sirius (-1.4)
- -0.5 to 0.0
- 0.0 to +0.5
- +0.5 to +1.0
- +1.0 to +1.5
- +1.5 to +2.0
- +2.0 to +2.5
- +2.5 to +3.0
- +3.0 to +3.5
- +3.5 to +4.0
- +4.0 to +4.5
- Fainter
- Variable star

Spectral types

- O-B
- A
- F
- G
- K
- M

Deep-sky objects

- Open star clusters
- Globular star clusters
- Bright diffuse nebulae
- Planetary nebulae
- Galaxies



Observer's note

MAY 2022

The night sky as it appears on 17 May 2023 at approximately 22:00 (BST)

© Getty Images; ESO

REVIEW

NIKON PROSTAFF P7 8x42

This small, premium binocular offers wide-angle, high-definition views of the stars that will have you feeling like you're floating in space

Reviewed by Gemma Lavender

BINOCULAR ADVICE

Cost: £209 / $189.95

Magnification: 8x

Objective lens diameter: 42mm

Angular field of view: 6.8 degrees

Eye relief: 20mm

Weight: 618 grams

ADDITIONAL KIT

- Carrying case
- Objective lens caps
- Neck strap
- Double eyepiece cover

Nikon's Prostaff P7 8x42 is a lightweight and affordable alternative to its P3 binoculars. When asked for the perfect binoculars for stargazing, astronomers often cite those with a magnification of at least 10x50. This makes perfect sense – the 10x magnification and 50mm aperture is an ideal combination of power and light-gathering ability. Sometimes the insistence on 10x50s can blind would-be users to the ability of smaller 8x42 instruments: with an 8x magnification and 42mm aperture, this stargazing aid can present wide star-strewn fields. But does Nikon's Prostaff P7 8x42 binocular do enough to challenge the hegemony of 10x50 instruments?

On first use, Nikon's Prostaff P7 8x42 binocular impresses with its sturdy compactness. Coated in a lovely rubber surface with subtle textures to ensure a safe grip, they're a delight to wield, weighing just 618 grams. Your arms won't get tired holding them – a burden of heavier, larger binoculars – and they can even be easily held in just one hand, making them perfect for the casual skywatcher. We were able to sweep the night sky for long periods of time.

We were delighted by the eye relief, which boasts a pleasant 20mm, and the extendable eye cups feature a lockable diopter adjustment. We discovered that we were able to 'save' our set-up so that we didn't have to keep adjusting them each time we used them for skywatching – a very useful feature that offered an easy 'grab-and-go' option as we observed over the course of several nights and headed indoors to warm up over a cup of hot chocolate during our sessions. The Prostaff P7 8x42 binocular comes with standard accessories: a neck strap, lens caps and a fabric case. All items are of excellent quality, while the lenses are multi-coated and the prisms feature highly reflective multi-layer optics.

We're very familiar with using 10x50 binoculars, so the performance of the Prostaff P7 8x42 binocular was a pleasant surprise. The binocular has a stated field of view at one kilometre (0.6 miles) of 126 metres (413 feet) for daytime use. We can translate this to a field of view of the night sky by dividing 126 by 17.5 – because one degree of the sky corresponds to 17.5 metres (57.4 feet) at a distance of 1,000 metres (3,280.8 feet) – giving a field of view of the

night sky of 7.2 degrees. For comparison, the angular diameter of the full Moon is about half a degree. We found this wide expanse to be wonderful as we swept through a sky littered with stars. Pointing at Orion (the Hunter), the three stars of the Hunter's belt – Alnitak, Alnilam and Mintaka – were sharp points of light, while below them the great Orion Nebula was a misty, white haze. Within the nebula, we were able to resolve the tight young stars of the Trapezium Cluster.

We turned to the open clusters of Auriga (the Charioteer) – Messiers 36, 37 and 38 – and were delighted by their sharp blue-white and ice-white coloured stars, albeit appearing a little faint, on a background of black velvet. More stunning was the Pleiades in the constellation of Taurus (the Bull), which we found to be dazzling through the Prostaff P7 8x42 binocular; dozens more stars popped into the field of view compared to what can be seen with the unaided eye. To our delight, we could also detect the Merope Nebula through the optical system.

We compared the view of the Pleiades through the Celestron UpClose G2 10x50 binocular we were using for comparison. The Celestron binocular has a stated angular field of 6.8 degrees, so still quite wide, but even the extra 0.4 degrees in the Nikon binocular was very noticeable. We strongly recommend just sitting back on a reclining garden chair and slowly sweeping through the star-rich Milky Way with this binocular. We also discovered that the wide field of view means that star patterns visible with the unaided eye are also visible through the binocular, helping us retain our bearings in a starry sky. While images were pin-sharp as we swept the heavens, we did detect some distortion at the edge of the field of view.

When we pointed the Prostaff P7 8x42 binocular towards Jupiter, which was beginning to slink towards the southwest at a magnitude of -2.1 in the early evening sky, we could just about make out Ganymede to the right of the gas giant's limb. Io and Callisto, closer in to Jupiter, and Europa, on the opposite flank, couldn't be seen, being too close to the planet at the time. Interestingly, the view in the 8x42 binocular

The Nikon Prostaff P7 8x42 binocular boasts an exquisite build

BEST FOR...

- £ MEDIUM BUDGETS
- CASUAL ASTRONOMERS
- LUNAR OBSERVING
- BRIGHT DEEP-SKY TARGETS
- PLANETARY OBSERVING

20mm of eye relief is a great boon for this binocular

"While images were pin-sharp as we swept the heavens, we did detect some distortion at the edge of the field of view"

The Prostaff P7 8x42 binocular features multi-coated lenses

was clearer than in the Celestron 10x50 we were using for comparison, as we struggled to make out Ganymede in the larger instrument.

All in all, the Prostaff P7 8x42 binocular belied its lower magnification and aperture to competitively perform next to some – admittedly much lower cost – 10x50 binoculars. Their compact and lightweight nature, coupled with a forgiving wide field, means that shake induced by wobbly arms is kept to a minimum. Over ten minutes, we discovered that our arms didn't get tired holding the Prostaff P7 8x42 binocular aloft – a huge boon for enjoyable prolonged use. Meanwhile, focusing is neat and smooth, and the binocular remains steadfast in focus once you've reached that point.

The Prostaff P7 8x42 binocular has another string to its bow, as it makes a wonderfully versatile all-rounder. Indeed, the binocular is primarily designed for daytime use, and distant trees, buildings, birds and aeroplanes all appear crystal clear through the field of view. If you are out and about in nature, perhaps on a camping holiday, the Nikon Prostaff P7 8x42 is a brilliant companion. Additionally, the binocular is fog-proof and waterproof up to a depth of one metre (3.3 feet) for a duration of ten minutes, though if there's that much water about, the chances are that the weather isn't suitable for astronomy anyway. However, this design means that the optical system fairs very well against condensation and dew – something we noticed would form when walking from a warm room, out into a frosty night and back in again when our observing sessions were over.

Although the Prostaff P7 8x42 is a little pricey – you can pick up a plethora of budget 10x50 binoculars for a quarter of the price – it does justify the cost somewhat. The binocular is extremely well made, and feels high quality when wielded. Meanwhile, views through the barrels are sharp and crystal clear. If you love just panning through the sky and soaking up the views of thousands of stars in an impressively wide field, then you'll greatly appreciate the Nikon Prostaff P7 8x42 binocular. However, given that you can pick up a decent Go-To beginner's telescope through which you can see much more for a little extra, you may feel that the price of the Nikon Prostaff P7 8x42 binocular is a little too high.

"The Prostaff P7 8x42 binocular belied its lower magnification and aperture to competitively perform next to some 10x50 binoculars"

FOR

- ⊕ Pin-sharp images
- ⊕ Lightweight for long observing sessions
- ⊕ Wide field of view
- ⊕ Dioptre lock
- ⊕ Versatile

AGAINST

- ⊖ Not suitable for detailed astronomy work
- ⊖ Expensive

GET READY TO BLAST OFF ON A JOURNEY ACROSS THE STARS!

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IN THE SHOPS: BEST TELESCOPE MOUNTS OF 2023

Sky-Watcher EQ5 Deluxe Mount and Tripod

Cost: £325 (approx. $402.65)
From: Sky-Watcher

1 Sky-Watcher's EQ5 mount's modest size, low cost and array of features have placed it among the most popular small telescope mounts ever produced. It's one of the most popular entry-level equatorial mounts. The EQ5 also comes as part of many small telescope packages, offering the option to purchase a complete telescope with a proper astronomical mounting. For an additional cost, dual-axis motor drives can be added, enabling a great platform into trying astrophotography. An optional polar scope is also available for fast and accurate polar alignment. The EQ5 is a highly capable portable mount and is easily capable of holding most small telescope tubes up to around eight-inch aperture.

Sky-Watcher EQ5 Pro Go-To Mount and Tripod

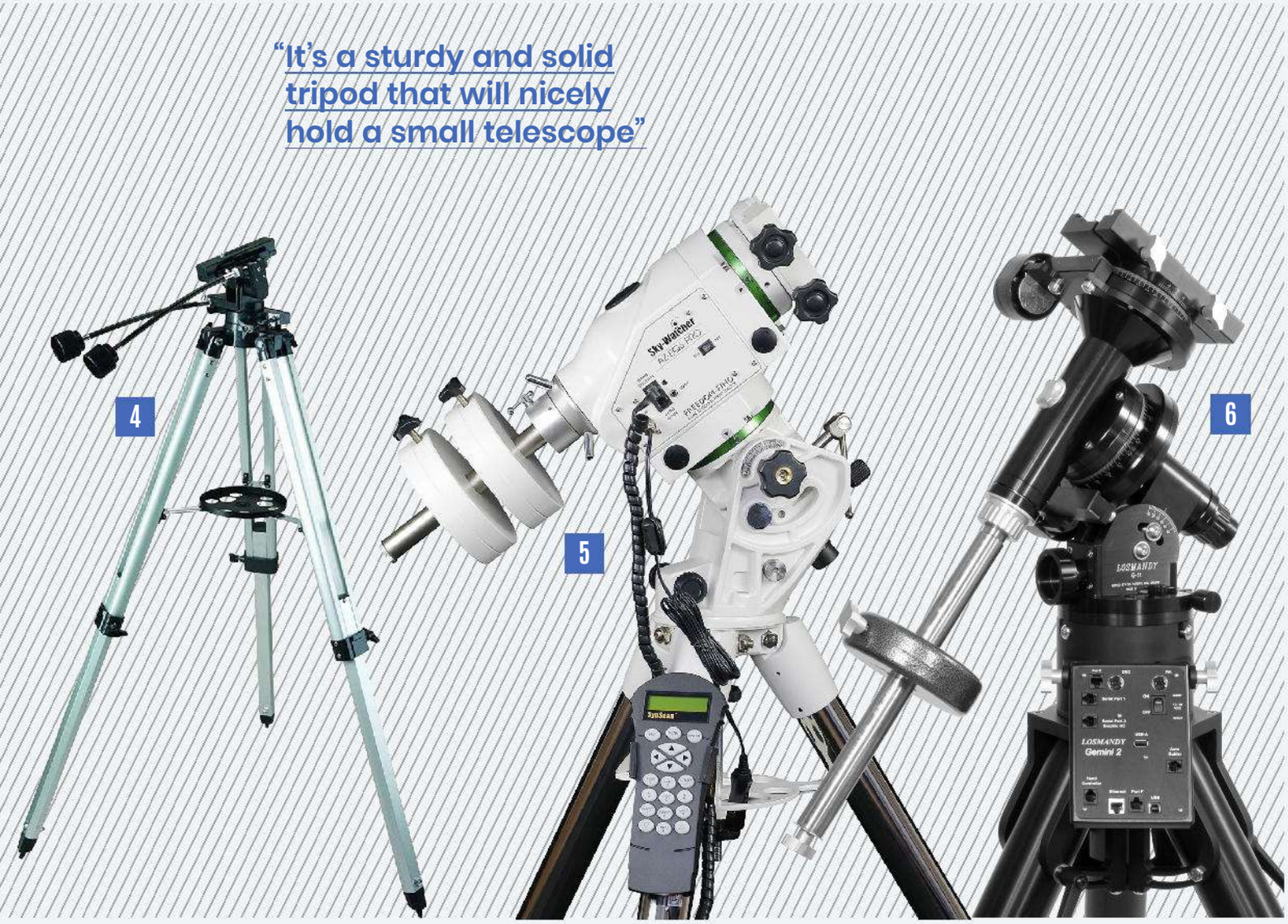
Cost: £733 (approx. $908.15)
From: Sky-Watcher

2 The fully computerised version of the EQ5 represents a great mount to venture into the world of astrophotography with. Along with dual-axis motor drives, it offers full Go-To capability with a large object database. Multiple tracking rates are available, as is an autoguider port for long-exposure deep-sky imaging. Refractors below five inches and reflectors below eight inches are the best fit for this mount. For example, it's perfectly capable of providing a solid platform for the highly popular eight-inch Schmidt-Cassegrain telescope designs. The EQ5 is also highly portable and is therefore an ideal choice for those without a permanent observing site.

Celestron Advanced VX Go-To Equatorial Mount

Cost: £897 / $1,277.95
From: Celestron

3 Celestron's Advanced VX offers an array of advanced features and a slightly increased payload capacity, meaning larger optical tubes can be used. For example, Celestron offers this mount as part of a package with its popular C8 Schmidt-Cassegrain, for which it is well suited. The slewing and tracking accuracy of the VX mount is also impressive, and the control system is very user-friendly and easy to get to grips with. The polar alignment method available using the telescope software is easily accomplished and results in accurate alignment. Overall, the VX mount is a great platform for most small telescopes and is one of the best available at its price point.



Celestron Heavy Duty Alt-Azimuth Tripod

Cost: £109 / $119.95
From: Celestron

4 The Celestron Heavy Duty tripod is an ideal entry-level mounting for binoculars or small telescopes. It offers manual slow-motion controls for fine adjustments and its standard mounting bracket allows quick attachment of many small telescopes, binoculars or cameras. Though it's the simplest entry here, it's a sturdy and solid tripod that will nicely hold a small telescope in the three to five inch aperture range. The addition of slow-motion controls is useful, especially for observing objects at higher magnifications. Overall, this is a nice low-cost mount for those just starting out or anyone looking for a quick 'grab-and-go' mount for a small telescope or binoculars.

Sky-Watcher AZ-EQ6GT Go-To Dual Mount

Cost: £1,699.99 / $2,670.00
From: Sky-Watcher

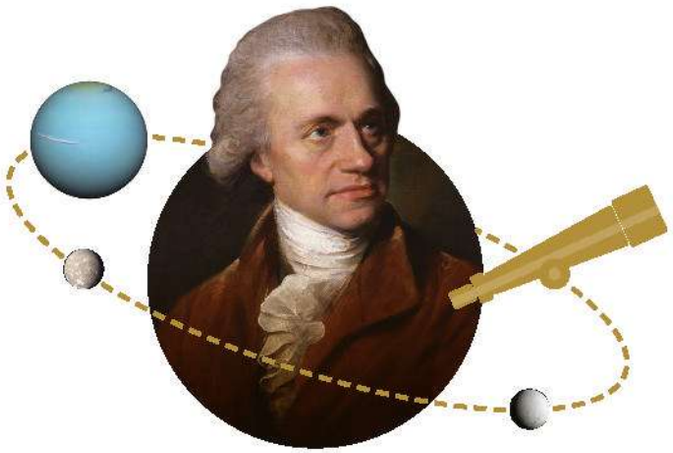
5 The AZ-EQ6GT mount has the ability to operate in either equatorial or alt-azimuth. This works well, and its decent payload capacity means many different telescopes can be mounted to it. The mount also has a neat feature of the user being able to move the telescope around manually without the mount losing its positional information, meaning it can be slewed using the motors or pushed by hand. The quoted payload capacity is impressive, and well above entry-level mounts such as the EQ5. The EQ6 in any form is a great choice for the more serious amateur astronomer, and this latest version is a great addition.

Losmandy G-11 Equatorial Mount

Cost: £3,998 / $3,395
From: Losmandy

6 The Losmandy G-11 is one of the most popular serious mounts of the past few decades. Its superb build quality and great performance has garnered a loyal following. The latest version offers dual-axis Go-To slewing via the Gemini 2 system. It can also carry larger telescopes and is an ideal platform for serious astrophotographers. Its flexibility, performance and build quality put it among the best serious mounts available. You can also order the mount with a high-quality polar alignment scope that allows fast and very accurate alignment for those who do not have a permanent observing site. Overall, it's a superb choice for the more serious or experienced observer.

HEROES OF SPACE



WILLIAM HERSCHEL

Scouring the heavens with his sister, Caroline, Herschel discovered Uranus and several Solar System moons

Born in Hanover, Germany, in 1738, in 1759 Herschel left Germany for England, where he taught music before becoming an organist. On 13 March 1781, Herschel noticed a small object that, over the course of several nights, was slowly moving across the sky. At first he thought he had discovered a comet, but further observations revealed that the object was a planet. Herschel lobbied to name the new body 'Georgium Sidus', after King George III, but it was eventually named Uranus after the Greek god of the sky. As a result of his discovery, the monarch knighted Herschel and appointed him to the position of court astronomer. The attached pension allowed him to conclude his musical career and focus his full attention on the skies. When Herschel was subsequently elected a member of the prestigious Royal Society, he received a copy of Charles Messier's *Catalogue of Nebulae and Star Clusters*, a list of diverse nebulae in the night sky. The catalogue piqued his interest, and he began to examine the fuzzy objects.

On 23 October 1783, he began a sky survey of his own, standing on a ladder while peering through his telescope and describing the objects he saw to his sister, Caroline. Over 20 years, he observed 2,500 new nebulae and star clusters and recorded them in his *Catalogue of Nebulae and Clusters of Stars*. The catalogue was enlarged and renamed the New General Catalogue; today many non-stellar objects are identified by their NGC numbers. Of the 7,840 nebulae and clusters in the catalogue today, 4,630 were discovered by Herschel and his son. The astronomer discovered several moons around the outer planets, locating Titania and Oberon around Uranus and Saturn's sixth and seventh moons, Enceladus and Mimas.

In 1800, Herschel performed a simple experiment determining the temperatures of the different colours of sunlight passed through a prism. He noticed the region just beyond the red colour was even higher than light in the visible spectrum, and used his measurements to deduce the presence of what is now known to be infrared radiation. The European Space Agency's infrared space observatory was subsequently named for him. Herschel proposed the name 'asteroids' for the large bodies discovered in 1801. He was elected vice president of the newly formed Royal Astronomical Society in 1820 and president the following year. His last published paper catalogued 145 double stars. Herschel died on 25 August 1822 at the age of 83 in Slough, England.

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ALL ABOUT SPACE

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